ELECTRONICS DEVICES AND CIRCUITS

OBJECTIVE

OPTICAL EXCITATION IN DIODE

PHOTODIODE

Photo Detectors

- Optical receivers convert optical signal (light) to electrical signal (current/voltage)
  - **Hence referred ‘O/E Converter’**
- Photodetector is the fundamental element of optical receiver, followed by amplifiers and signal conditioning circuitry
- There are several photodetector types:
  - **Photodiodes, Phototransistors, Photon multipliers, Photo-resistors etc.**

Photodetector Requirements

- Good sensitivity (responsivity) at the desired wavelength and poor responsivity elsewhere → wavelength selectivity
- Fast response time → high bandwidth
- Compatible physical dimensions
- Low noise
- Insensitive to temperature variations
- Long operating life and reasonable cost

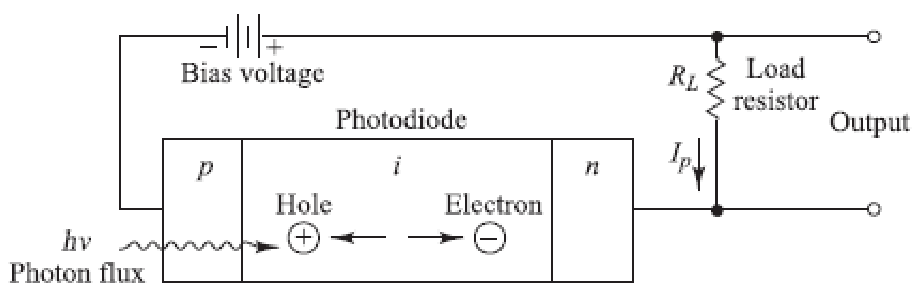
Photodiodes

- Due to above requirements, only *photodiodes* are used as photo detectors in optical communication systems
- Positive-Intrinsic-Negative (*pin*) photodiode
  - **No internal gain**
- Avalanche Photo Diode (*APD*)
  - **An internal gain of *M* due to self multiplication**
- Photodiodes are sufficiently *reverse biased* during normal operation → no current flow, the intrinsic region is fully depleted of carriers

Physical Principles of Photodiodes

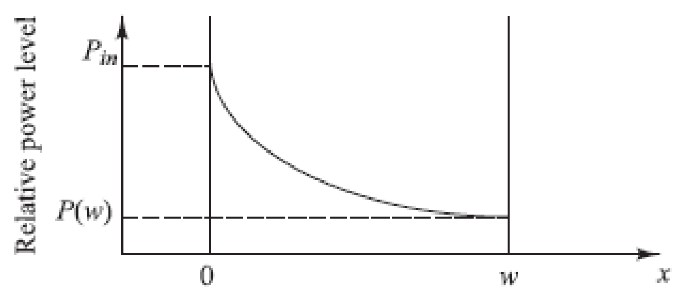
- As a photon flux Φ penetrates into a semiconductor, it will be absorbed as it progresses through the material.
- If $\alpha_s(\lambda)$ is the photon absorption coefficient at a wavelength λ, the *power level at a distance x into the*

$$P(x) = P_{in}\exp(-\alpha_s x)$$



Absorbed photons trigger *photocurrent* I_p in the external circuitry

Photocurrent ∝ Incident Light Power



Examples of Photon Absorption

Example 6.1 If the absorption coefficient of $In_{0.53}Ga_{0.47}As$ is 0.8 μm^{-1} at 1550 nm, what is the penetration depth at which $P(x)/P_{in} = 1/e = 0.368$?

Solution: From Eq. (6.1),

$$\frac{P(x)}{P_{in}} = \exp(-\alpha_s x) = \exp[(-0.8)x] = 0.368$$

Therefore

$$-0.8\,x = \ln 0.368 = -0.9997$$

which yields $x = 1.25$ μm.

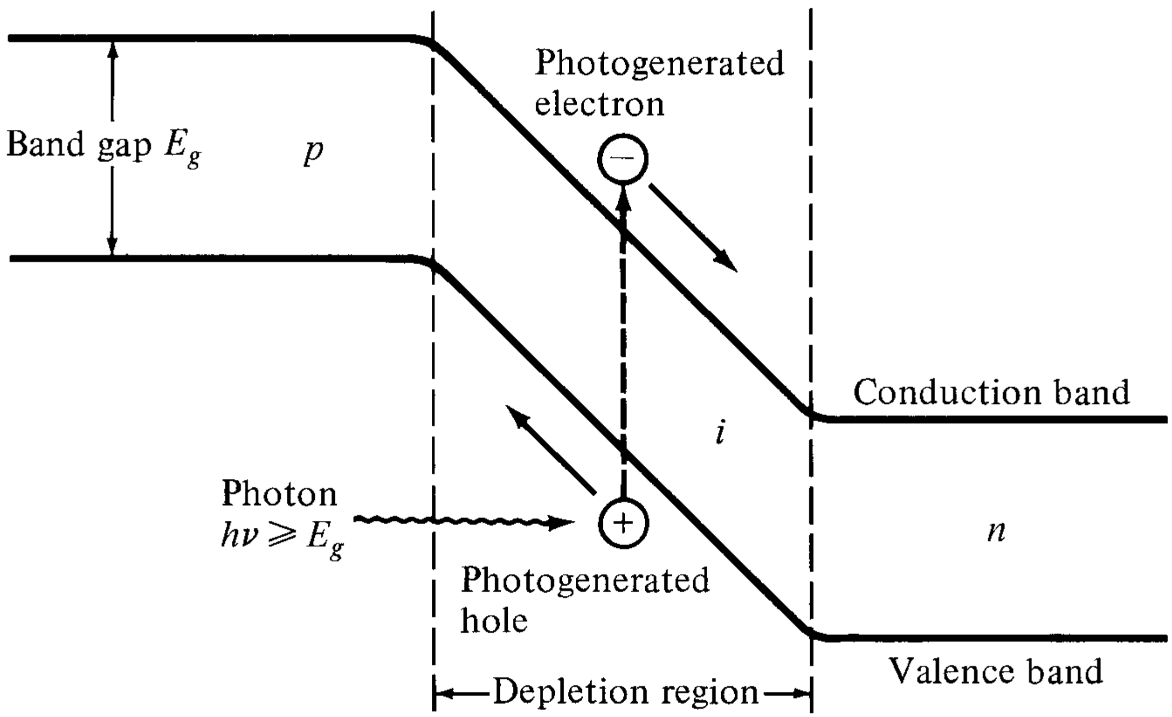
Example 6.2 A high-speed $In_{0.53}Ga_{0.47}As$ *pin* photodetector is made with a depletion layer thickness of 0.15 μm. What percent of incident photons are absorbed in this photodetector at 1310 nm if the absorption coefficient is 1.5 μm^{-1} at this wavelength?

Solution: From Eq. (6.1), the optical power level at $x = 0.15$ μm relative to the incident power level is

$$\frac{P(0.15)}{P_{in}} = \exp(-\alpha_s x) = \exp[(-1.5)0.15] = 0.80$$

Therefore only 20 percent of the incident photons are absorbed.

pin energy-band diagram



$$\lambda_c = \frac{hc}{E_g} = \frac{1.24}{E_g(eV)} \ \mu\text{m}$$

Cut off wavelength depends on the band gap energy

Quantum Efficiency

- The *quantum efficiency* η is the number of the electron–hole carrier pairs generated per incident–absorbed photon of energy *hv* and is given by

$$\eta = \frac{\text{number of electron–hole pairs generated}}{\text{number of incident–absorbed photons}} = \frac{I_p / q}{P_{in} / hv}$$

I_p is the photocurrent generated by a steady-state optical power P_{in} incident on the photodetector.

Avalanche Photodiode (APD)

- APD has an internal gain obtained by having a *high electric field* that energizes photo-generated electrons and holes
- These electrons and holes ionize bound electrons in the valence band upon colliding with them
- This mechanism is known as *impact ionization*
- The newly generated electrons and holes are also accelerated by the high electric field and they gain enough energy to cause further impact ionization
- This phenomena is called the avalanche effect

APD Vs PIN

- APD has high gain due to self multiplying mechanism, used in high end systems
- The tradeoff is the ‘excess noise’ due to random nature of the self multiplying process.
- APD’s need high reverse bias voltage (Ex: 40 V)
- Therefore costly and need additional circuitry

Responsivity ($\Re$)

Quantum Efficiency (η) = number of e-h pairs generated / number of incident photons

$$\eta = \frac{I_p / q}{P_0 / h\nu} \rightarrow \Re = \frac{I_p}{P_o} = \frac{\eta q}{h\nu} = \frac{\eta\lambda}{1.24}$$ mA/mW

$$\Re_{APD} = \Re_{PIN} M$$

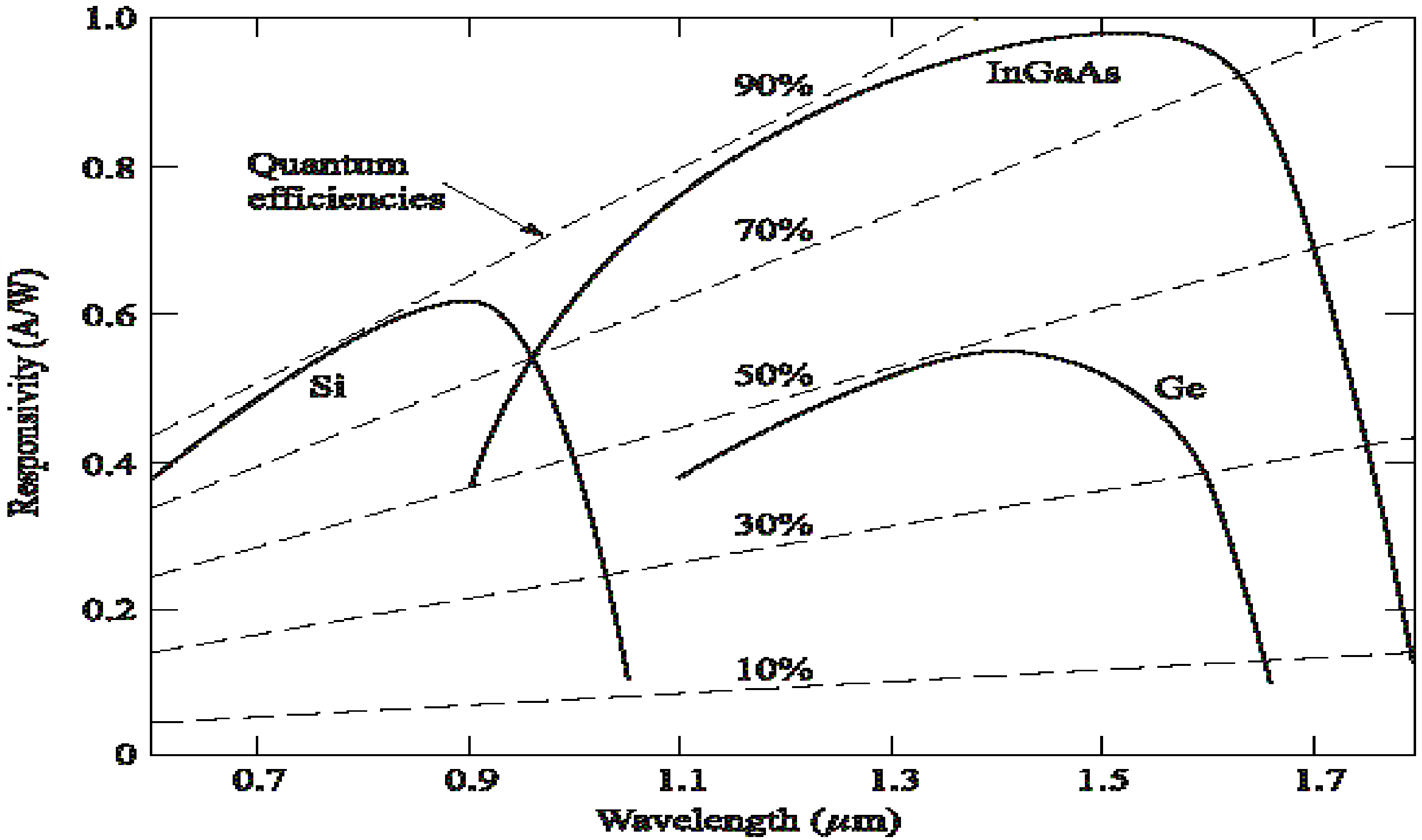
Avalanche PD's have an internal gain *M*

$$M = \frac{I_M}{I_p}$$

I_M: average value of the total multiplied current
M = 1 for *PIN* diodes

Responsivity

$$\Re = \eta\lambda / 1.24$$



When $\lambda << \lambda_c$ absorption is low
When $\lambda > \lambda_{c;}$ no absorption

$$\lambda_c = \frac{hc}{E_g} = \frac{1.24}{E_g(eV)} \ \mu\text{m}$$

Light Absorption Coefficient

- The upper wavelength cutoff is determined by the bandgap energy E_g of the material.

- At the lower-wavelength end, the photo response cuts off as a result of the very large values of α_s.