



# **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

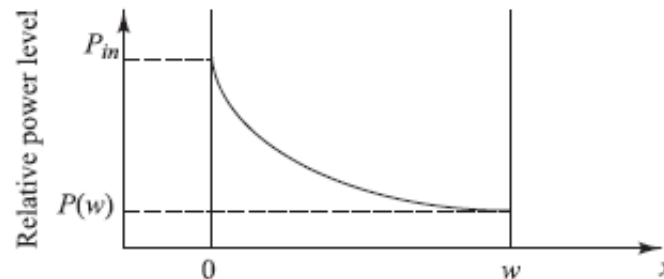
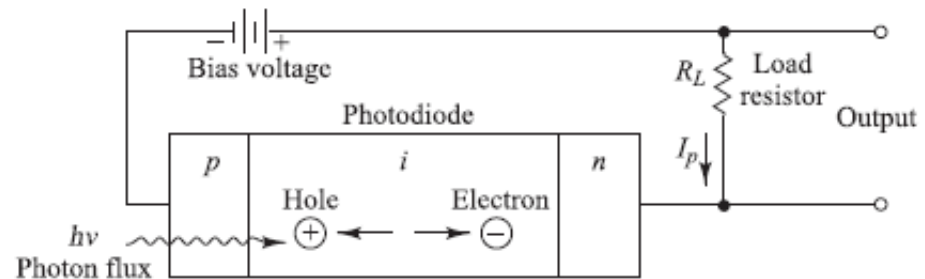
# Physical Principles of Photodiodes

- As a photon flux  $\Phi$  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  $\lambda$ , 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  $\propto$  Incident Light Power



# Examples of Photon Absorption

**Example 6.1** If the absorption coefficient of  $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$  is  $0.8 \mu\text{m}^{-1}$  at 1550 nm, what is the penetration depth at which  $P(x)/P_{in} = 1/e = 0.368$ ?

**Solution:** From Eq. (6.1),

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

Therefore

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

which yields  $x = 1.25 \mu\text{m}$ .

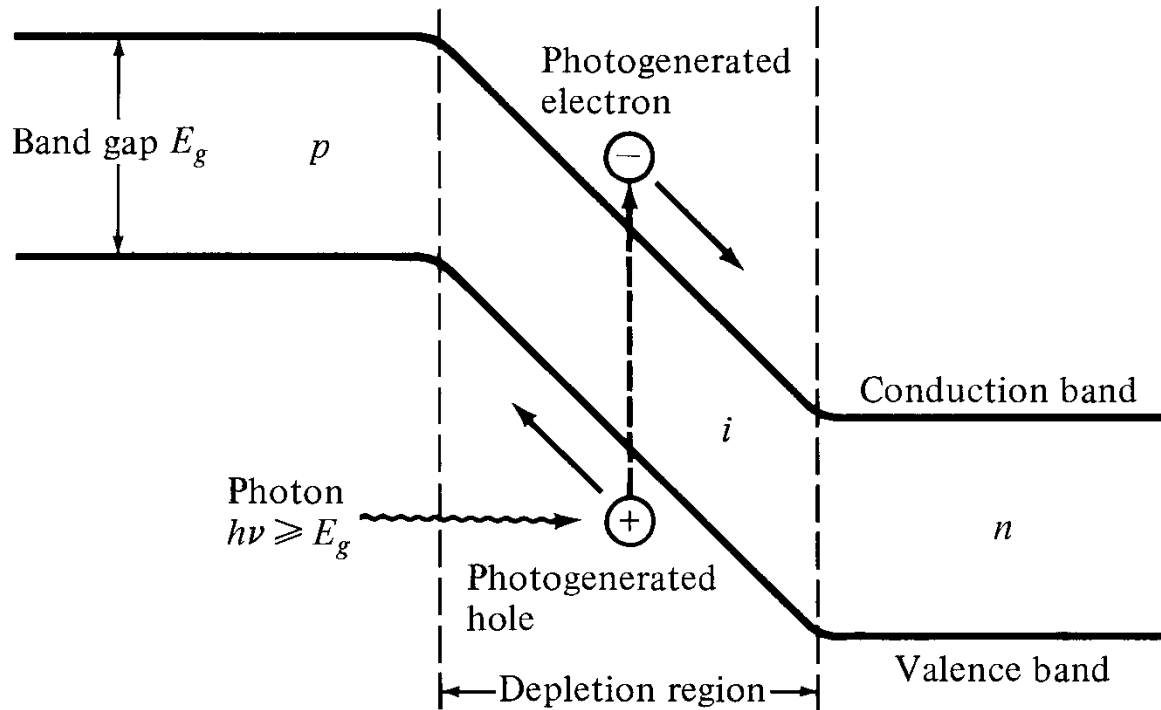
**Example 6.2** A high-speed  $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$  *pin* photodetector is made with a depletion layer thickness of  $0.15 \mu\text{m}$ . What percent of incident photons are absorbed in this photodetector at 1310 nm if the absorption coefficient is  $1.5 \mu\text{m}^{-1}$  at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

**Solution:** From Eq. (6.1), the optical power level at  $x = 0.15 \mu\text{m}$  relative to the incident power level is

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

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*  $\eta$  is the number of the electron–hole carrier pairs generated per incident–absorbed photon of energy  $h\nu$  and is given by

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

$I_p$  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 ( $\mathcal{R}$ )

Quantum Efficiency ( $\eta$ ) = number of e-h pairs generated / number of incident photons

$$\eta = \frac{I_p / q}{P_o / h\nu} \rightarrow \mathcal{R} = \frac{I_p}{P_o} = \frac{\eta q}{h\nu} = \frac{\eta \lambda}{1.24} \text{ mA/mW}$$

Avalanche PD's have an internal gain  $M$

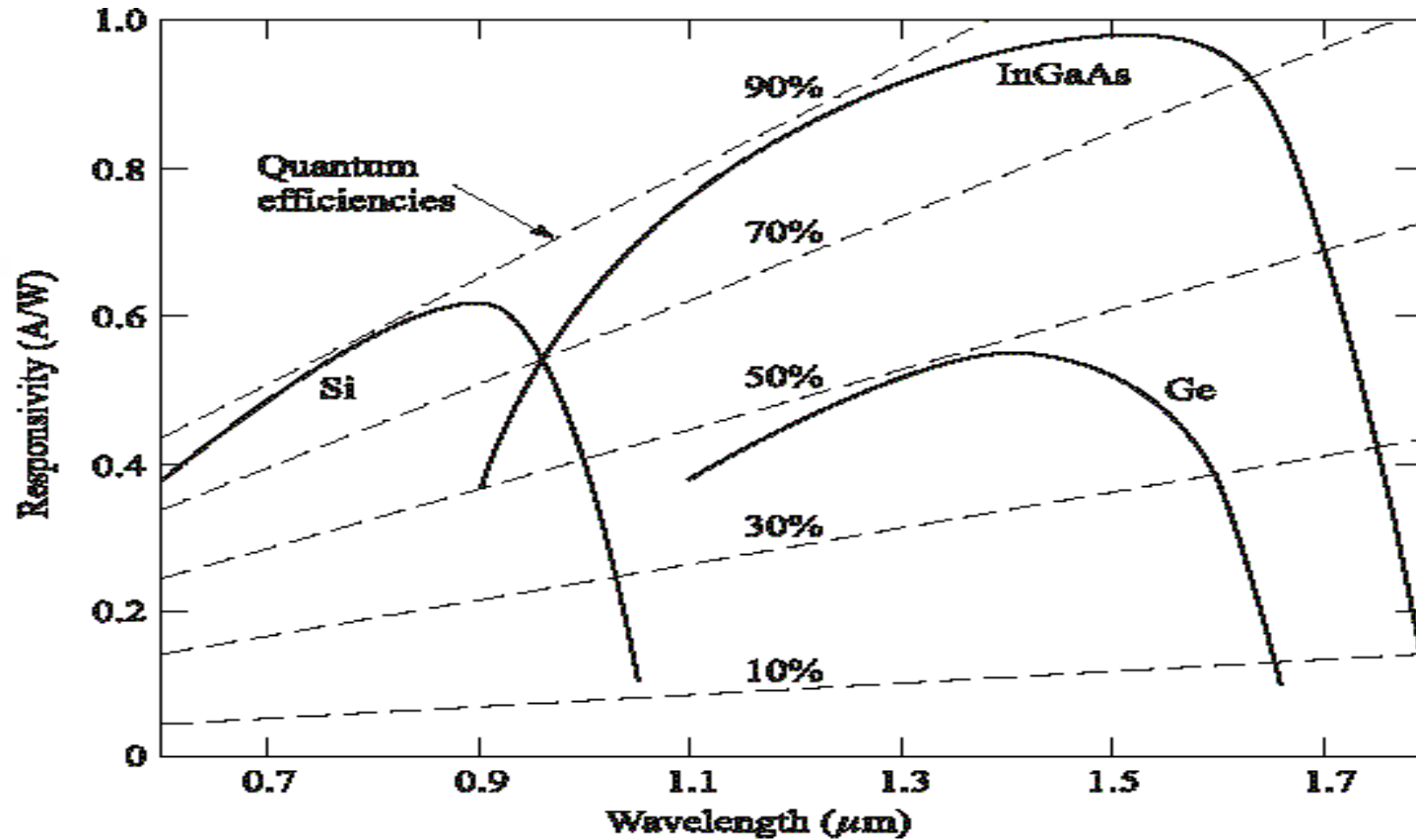
$$\mathcal{R}_{APD} = \mathcal{R}_{PIN} M$$

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

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

# Responsivity

$$\mathcal{R} = \eta \lambda / 1.24$$



When  $\lambda \ll \lambda_c$  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  $\alpha_s$ .

