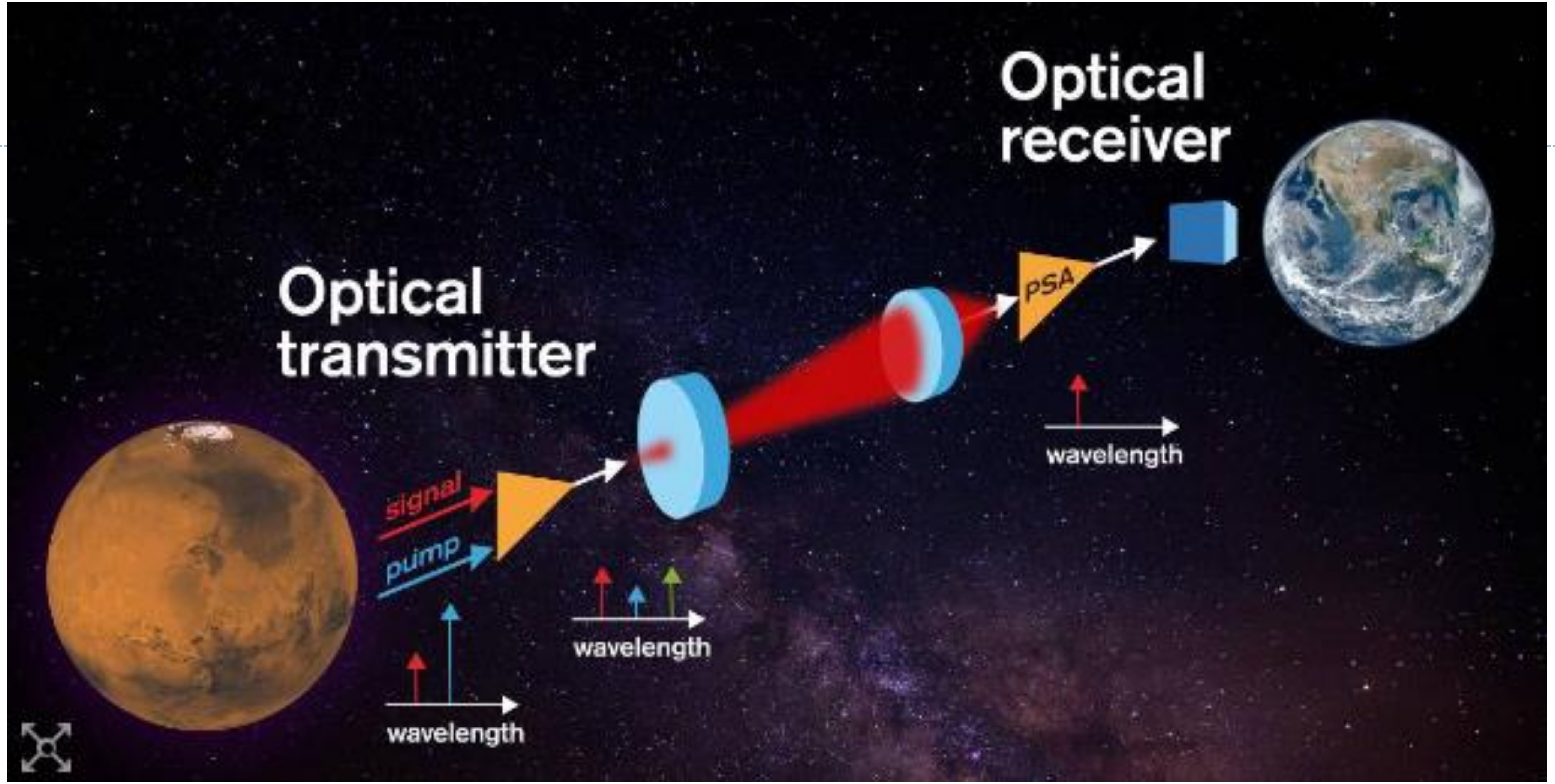


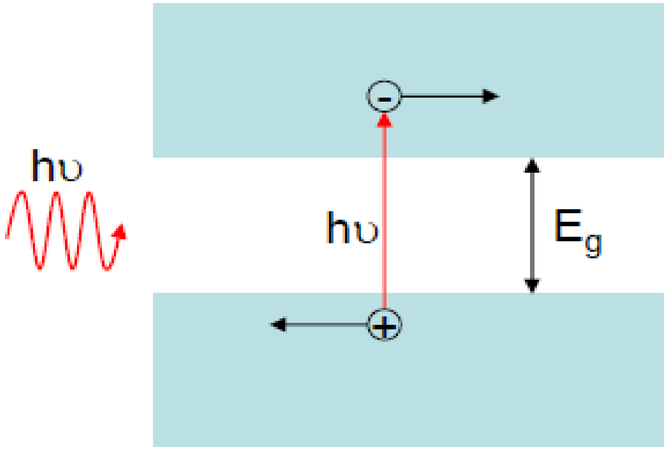
Module – 4
Optical Receivers

Optical Detectors

- High Sensitivity at wavelength of interest
- High fidelity
- Fast Response speed/Sufficient BW
- Insensitive to temperature variations
- Compatible with dimensions of fiber
- Minimum addition of noise to the system
  - Shot noise
  - Receiver thermal noise
  - Beat noise
- PIN Photodiodes, Avalanche Photodiodes
- Direct detection / Coherent detection

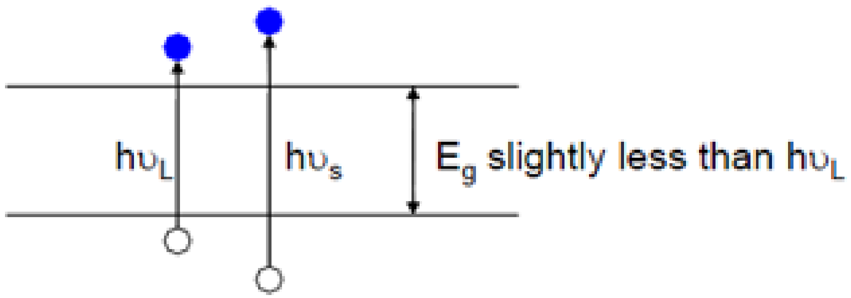
Electron-hole photogeneration

- Most modern photodetectors operate on the basis of the internal photoelectric effect – the photoexcited electrons and holes remain within the material, increasing the electrical conductivity of the material
- Electron-hole photogeneration in a semiconductor
- Absorbed photons generate free electron- hole pairs
- Transport of the free electrons and holes upon an electric field results in a current



Choice of photodiode materials

- A photodiode material should be chosen with a bandgap energy slightly less than the photon energy corresponding to the longest operating wavelength of the system.
- This gives a sufficiently high absorption coefficient to ensure a good response, and yet limits the number of thermally generated carriers in order to attain a low "dark current" (i.e. current generated with no incident light).
- Germanium photodiodes have relatively large dark currents due to their narrow bandgaps in comparison to other semiconductor materials.
- This is a major shortcoming with the use of germanium photodiodes, especially at shorter wavelengths (below 1.1 μm)



Junction photodiodes

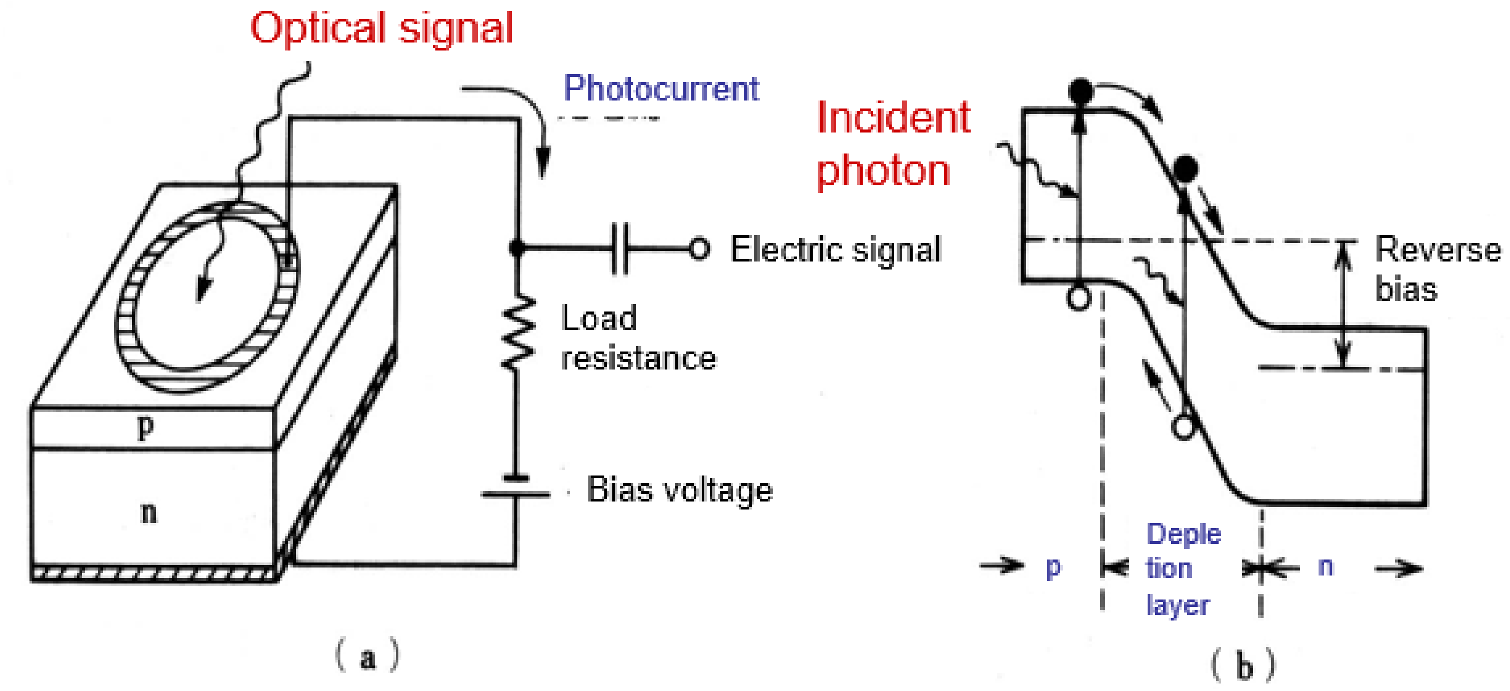
- The semiconductor photodiode detector is a p-n junction structure that is based on the internal photoeffect.

- The photoresponse of a photodiode results from the photogeneration of electron-hole pairs through band-to-band optical absorption.

- The threshold photon energy of a semiconductor photodiode is the bandgap energy Eg of its active region.

- The photogenerated electrons and holes in the depletion layer are subjected to the local electric field within that layer. The electron/hole carriers drift in opposite directions. This transport process induces an electric current in the external circuit.

Working principle of photodiodes



Structure and band diagram of photo-diode

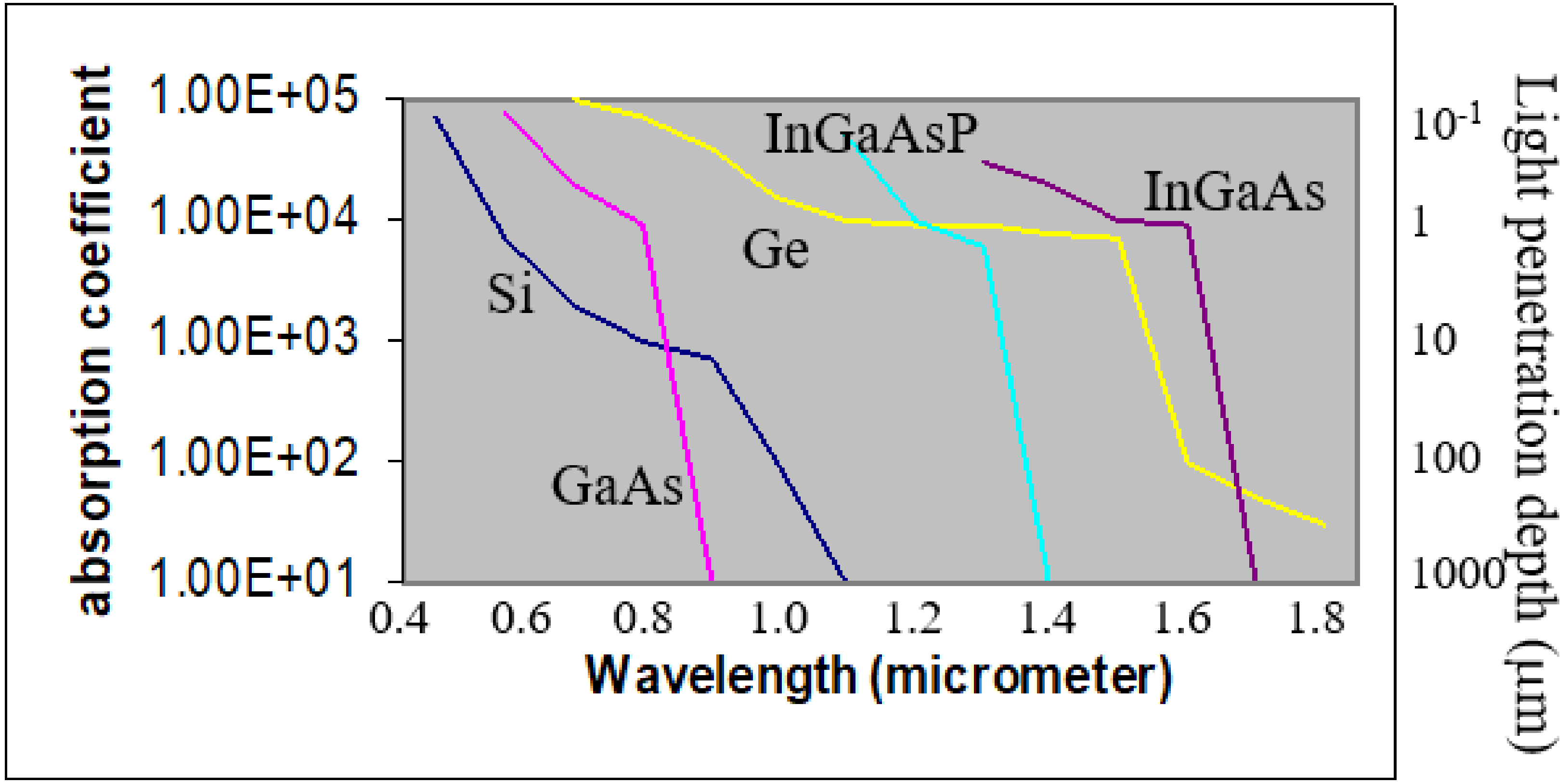
Why Photodiode detectors are usually operated in the strongly reverse-biased mode?

- A strong reverse bias creates a strong electric field in the junction that increases the drift velocity of the carriers, thereby reducing transit time

- A strong reverse bias increases the width of the depletion layer (W+D), thereby reducing the junction capacitance and improving the response time

- The increased width of the depletion layer leads to a larger photosensitive area, making it easier to collect more light.

Absorption characteristics



Numerical Problem

- A GaAS photodiode has a bandgap energy of 1.43 eV at 300 K. Calculate the cut-off wavelength.

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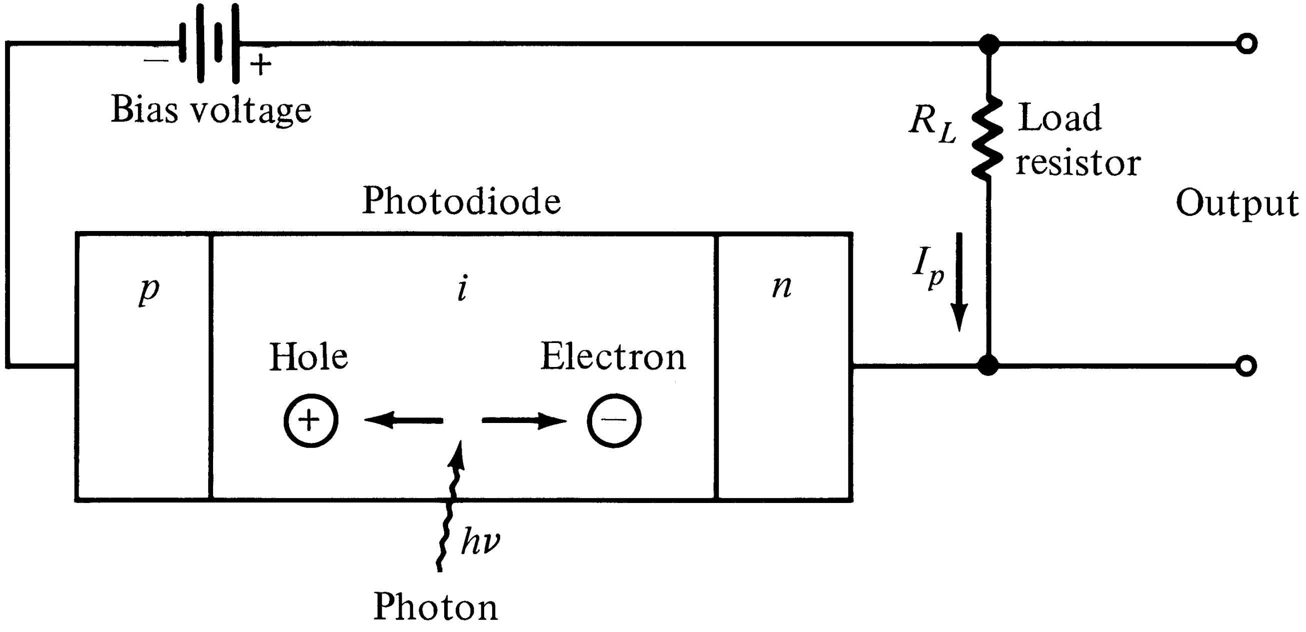
$$\lambda_c = \frac{hc}{E_g} = 869nm$$

Pin photodiode circuit

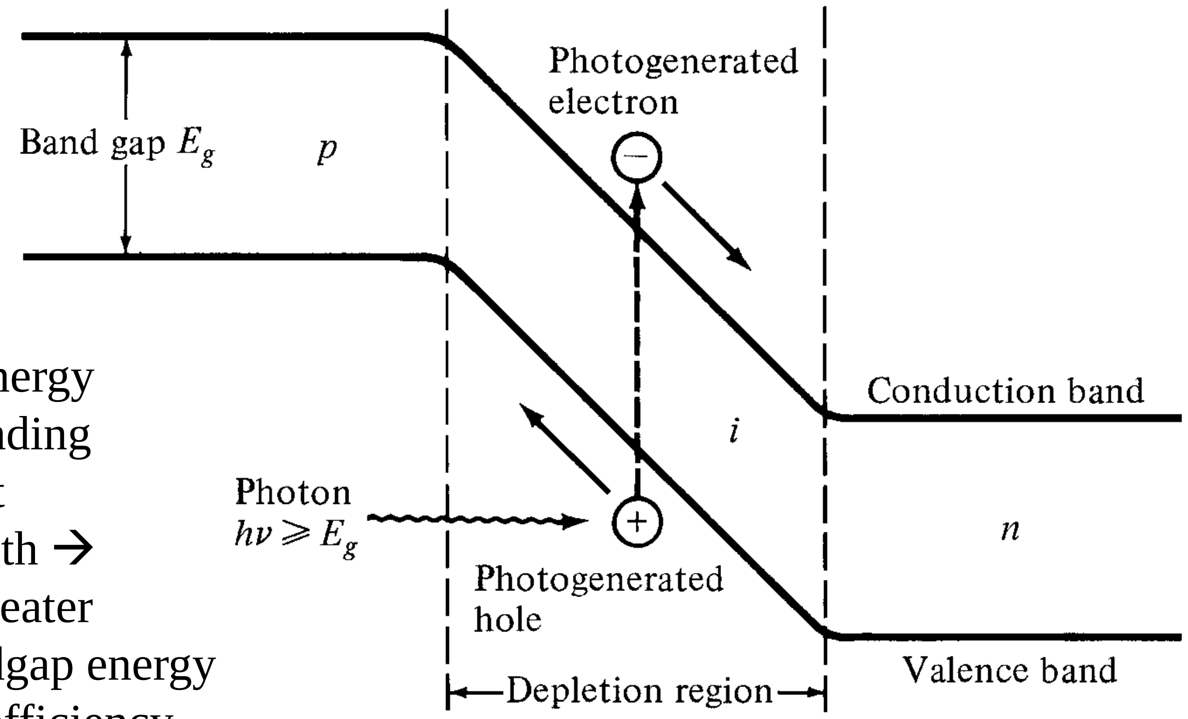


- p-i-n photodiode consists of an intrinsic region sandwiched between heavily doped p+ and n+ regions. The depletion layer is almost completely defined by the intrinsic region.

- In practice, the intrinsic region does not have to be truly intrinsic but only has to be highly resistive (lightly doped p or n region).

Energy-band diagram (Why reverse bias ?)

Photon energy
corresponding
to longest
wavelength →
slighly greater
than bandgap energy
for high efficiency
& low dark current



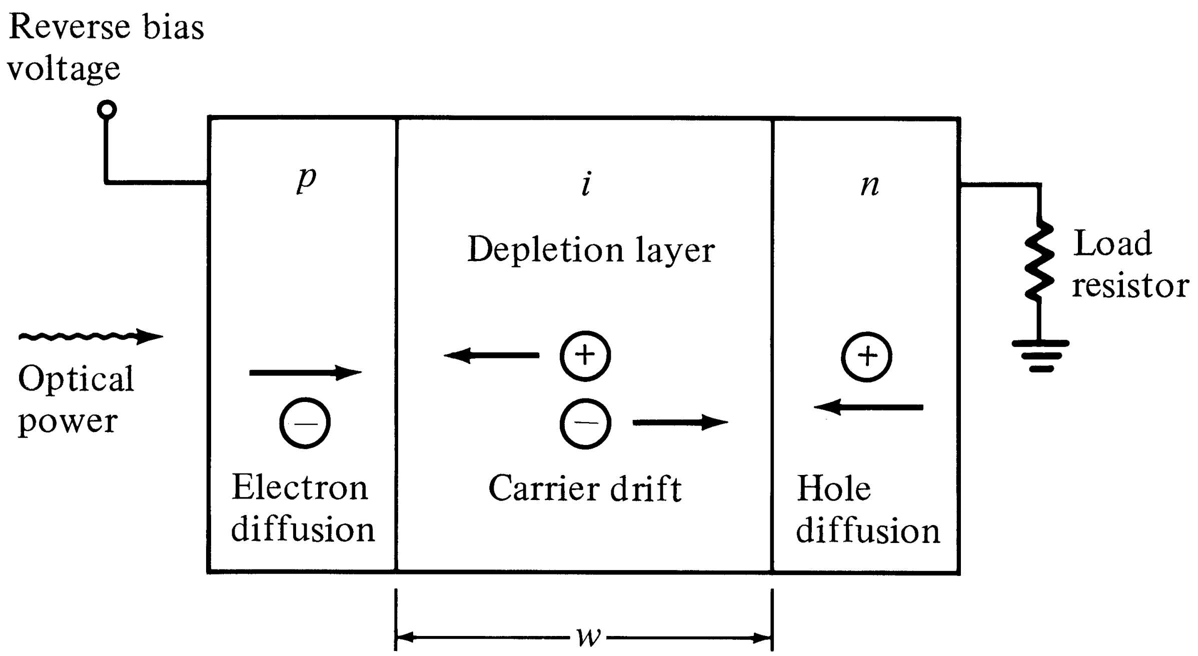
Advantages of p-i-n photodiodes

- Increasing the width of the depletion layer which increases the area available for capturing light

- Increasing the width of the depletion layer reduces the junction capacitance and thereby the RC time constant.

- Reducing the ratio between the diffusion length and the drift length of the device results in a greater proportion of the generated current being carried by the faster drift process.

Reverse-biased pin photodiode



$$P(w) = P_o [1 - \exp(-\alpha_s w)]$$

$$I_p = (q/h\nu) P_o [1 - \exp(-\alpha_s w)] (1-R_f)$$

$R_f \rightarrow$ reflectivity of detector surface

Quantum Efficiency & Responsivity

- $$\eta = \frac{\text{number of electrons collected}}{\text{number of incident photons}} = \frac{I_p/q}{P_o/h\upsilon}$$

- Responsivity $\Re$ $= I_p / P_o$ (A/W)

  $= \eta q / h\upsilon$ $= \eta q \lambda / hc$

- $\eta < 1$ for pin photodiode ; $\Re < 1$

- Upper cutoff → $\lambda_c = hc/E_g$

Numerical Problem

- In a 100ns pulse, 6*10^6 photons at a wavelength 1300 nm absorbed by a InGaAs photodetector. On the average 3.9*10^6 electron hole pairs are generated. Calculate the quantum efficiency

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$$\eta = 0.65 = 65\%$$

Numerical Problem

- Photons of energy $1.53*10^{-19}$ J are incident on a photodiode which has a responsivity of 0.65 A/W. If the optical power level is 10 μW, calculate the generated photocurrent.

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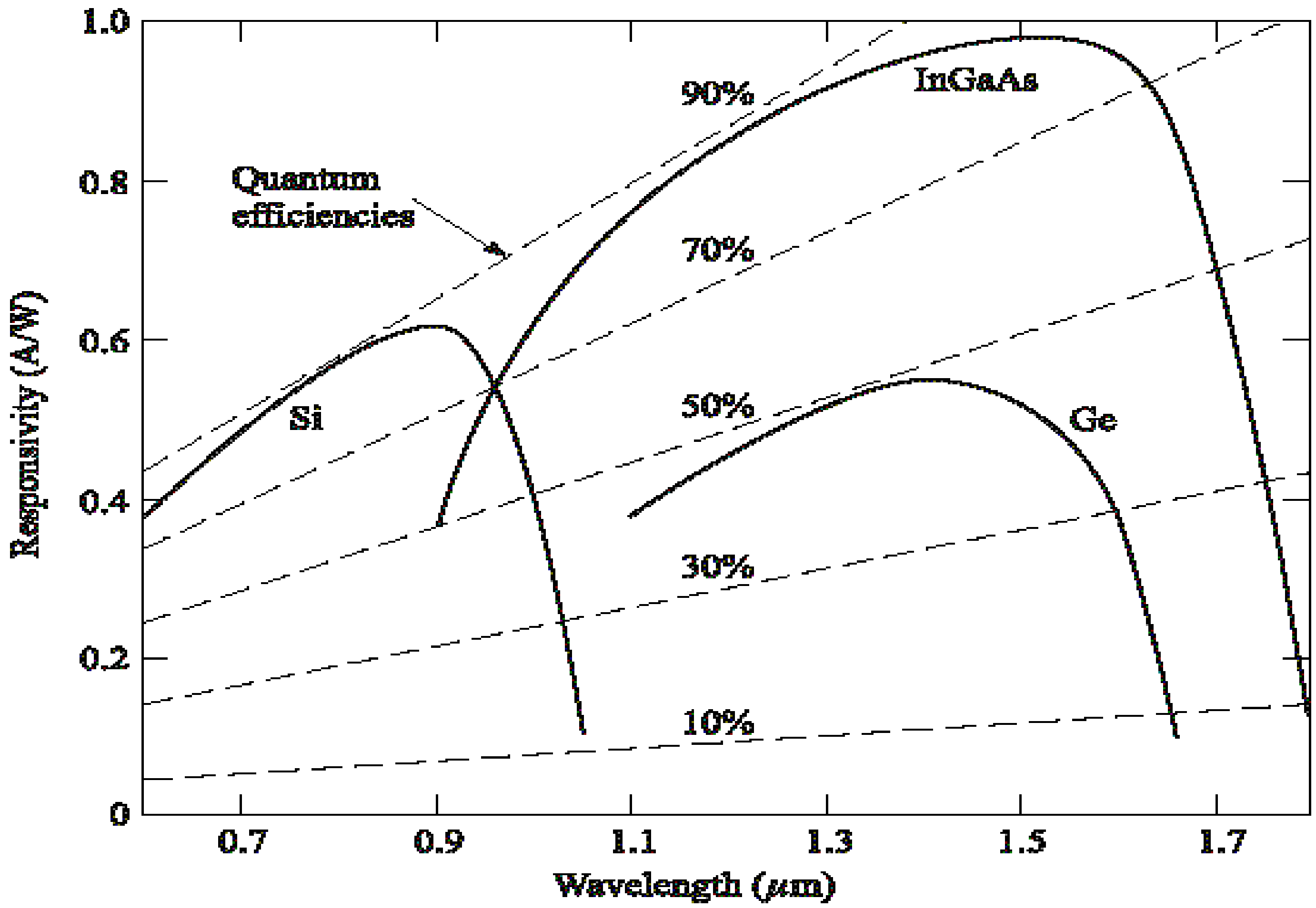
$$I_p = RP_0 = 6.5\mu A$$

Photodiode Responsivities



Numerical Problem

- In the above figure, for the wavelength range 1100 nm < λ < 1600 nm, the quantum efficiency for InGaAS diode is about 60 %. Calculate the responsivity in this wavelength.

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$$R = \frac{\eta q}{h\nu} = 4.83*10^{\wedge}5\lambda$$

$$R = 0.63 A/W$$

Numerical Problem

- When 3*10^11 photons each with a wavelength of 0.85 μm are incident on a photodiode, on average 1.2*10^11 electrons are collected at the terminals of the diode. Determine the quantum efficiency and responsivity of the photodiode at 0.85 μm.

Numerical Problem

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$$\eta = 0.4 = 40\%$$

$$R = \frac{\eta q}{h\nu} = 0.274 A/W$$