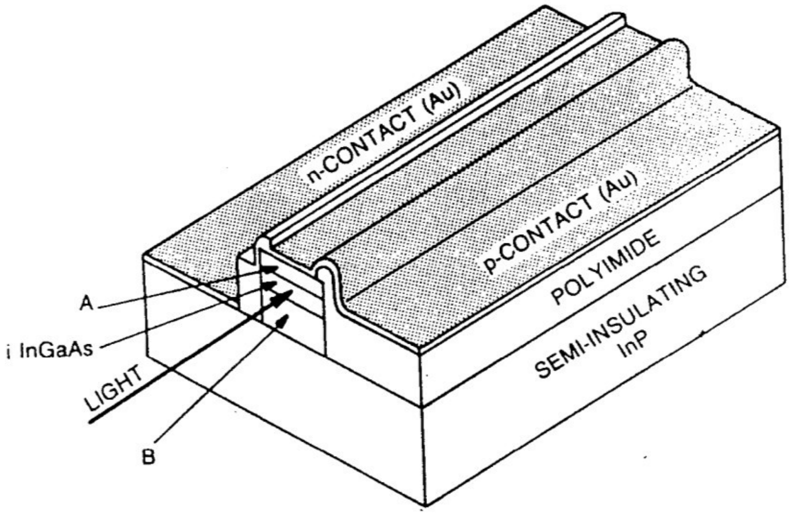
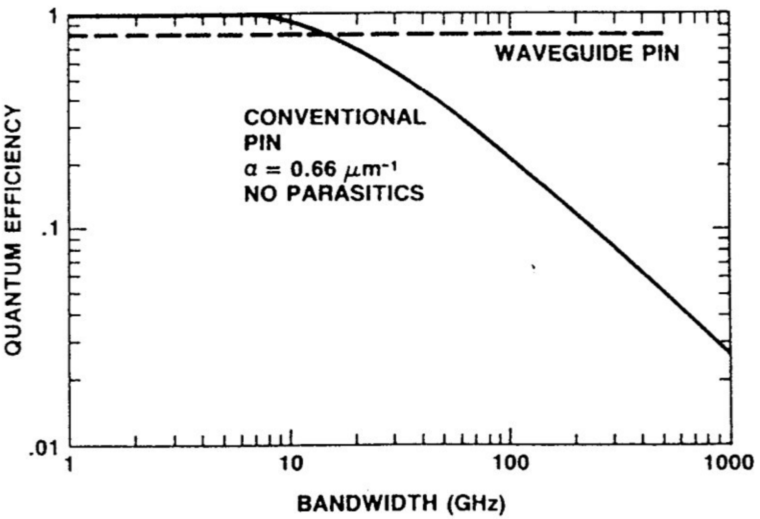
Unit-4

Lecture -5

Waveguide Photo detector, Transit Time, Capacitance, B.W., Dark Current, Signal to noise ration

Waveguide Photodetectors





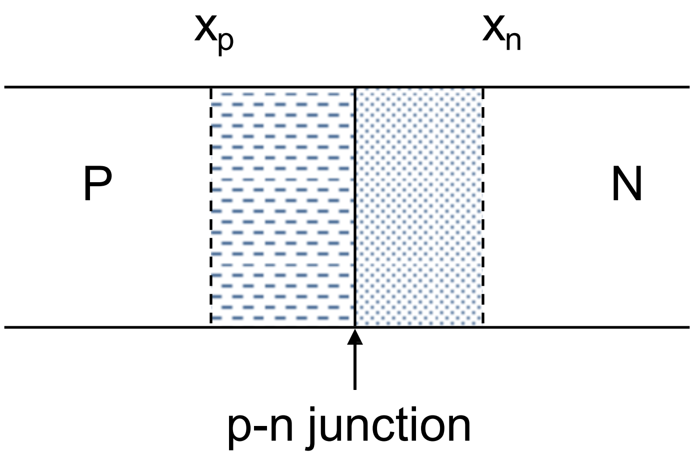
- *Waveguide detectors are suited for very high bandwidth applications*
- *Overcomes low absorption limitations*
- *Eliminates carrier generation in field free regions*
- *Decouples transit time from quantum efficiency*
- *Low capacitance*
- *More difficult optical coupling*

Carrier transit time

Transit time is a function of depletion width and carrier drift velocity

$t_d = w/v_d$

Detector Capacitance



$$C = \frac{\varepsilon A}{W} \qquad W = x_p + x_n$$

For a uniformly doped junction

$$C = \frac{A}{2}\left[\frac{2q\varepsilon}{V_o - V_{bi}} N_d\right]^{1/2}$$

$$W = \left[\frac{2\varepsilon(V_o - V_{bi})}{qN_d}\right]^{1/2}$$

Where: ε=permitivity q=electron charge

N_d=Active dopant density

V_o=Applied voltage V_{bi}=Built in potential

A=Junction area

Capacitance must be minimized for high sensitivity (low noise) and for high speed operation

Minimize by using the smallest light collecting area consistent with efficient collection of the incident light

Minimize by putting low doped "I" region between the P and N doped regions to increase W, the depletion width

W can be increased until field required to fully deplete causes excessive dark current, or carrier transit time begins to limit speed.

Bandwidth limit

$C=\varepsilon_0 K\ A/w$

where K is dielectric constant, A is area, w is depletion width, and ε_0 is the permittivity of free space (8.85 pF/m)

$B = 1/2\pi RC$

PIN Bandwidth and Efficiency Tradeoff

Transit time

$\tau = W / v_{sat}$

v_{sat}=saturation velocity=2×10^7 cm/s

R-C Limitation

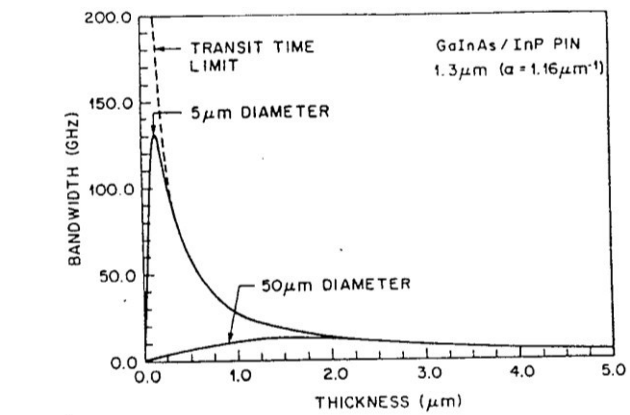
$$\tau_{RC} = R_{in} \frac{\varepsilon A}{W}$$

Responsivity

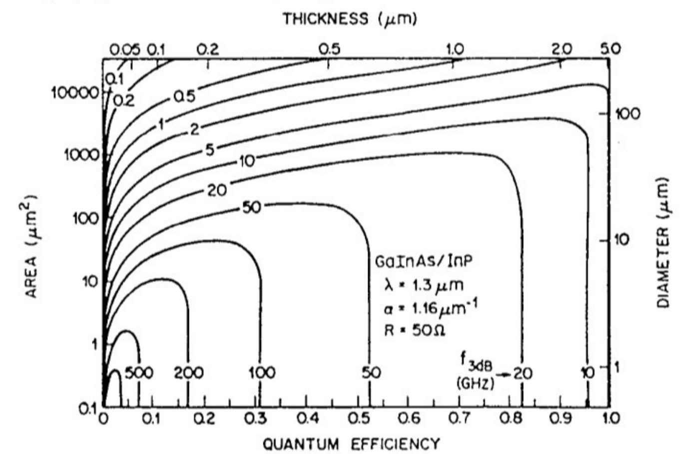
$$R = \frac{q}{h\nu}\left(1 - R_p\right)\left[1 - e^{-\alpha W}\right]$$

Diffusion

τ=4 ns/µm (slow)



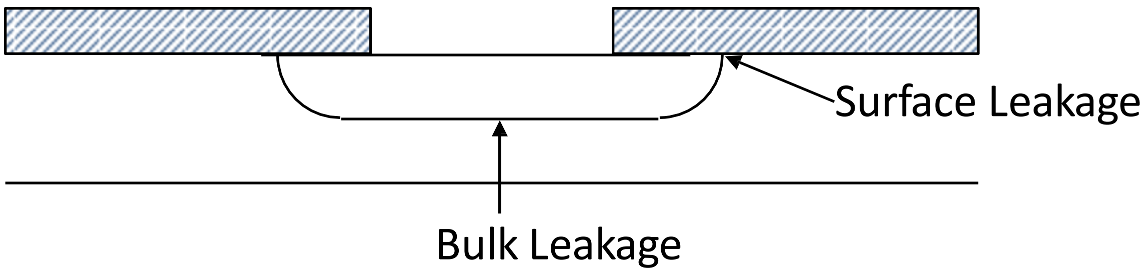
GaInAs p-i-n detector bandwidth dependence on depletion-layer thickness for 5 and 50 µm diameters. (α = 1.16 µm (1.3-µm wavelength) $v_n = 6.5 \times 10^6$ cm/s, $v_p = 4.8 \times 10^6$ cm/s.)



Contours of constant 3-dB bandwidth in the detector-area, depletion-layer-thickness plane. (α = 1.16 µm^{-1}, (1.3-µm wavelength), $v_n = 6.5 \times 10^6$ cm/s, $v_p = 4.8 \times 10^6$ cm/s, ϵ = 14.1.)

(Bowers1987)

Dark Current



Surface Leakage

Ohmic Conduction

Generation-recombination
via surface states

Bulk Leakage

Diffusion

Generation-Recombination

Tunneling

Usually not a significant noise source at high bandwidths for PIN Structures
High dark current can indicate poor potential reliability
In APDs its multiplication can be significant

Signal to Noise Ratio

$$\frac{S}{N} = \frac{\langle i_p^2 \rangle M^2}{2q(I_p + I_D)M^2 F(M)B + 2qI_L B + 4k_B TB / R_L}$$

i_p= average signal photocurrent level

based on modulation index m where

$$\langle i_p^2 \rangle = \frac{m^2 I_p^2}{2}$$

Optimum value of M

$$M_{opt}^{x+2} = \frac{2qI_L + 4k_B T / R_L}{xq\left(I_p + I_D\right)}$$

where F(M) = M^x and m=1