Photodetectors
Read: Kasip, Chapter 5
Yariv, Chapter 11
Class Handout

ECE 162C

Lecture #15

Prof. John Bowers

No class Monday (Memorial Day)

No class Wednesday

Class Friday, May 30

Types of Photodetectors

- Photoelectric detectors
  - A photon creates an electron-hole pair
  - Quantum detectors (single photon detection possible)
- Photoemission detectors
  - A photon causes the emission on an electron
- Thermal detectors
  - A photon causes a temperature rise
  - Wide spectral range (far IR to UV)
- Weak interaction Detectors
  - No photon absorption

Types of Photodetectors

- Photoelectric detectors
  - Photovoltaic (PIN)
  - Photoconductive
  - Avalanche photodetector (APD)
  - Phototransistor
- Photoemission detectors
  - Vacuum photodiode
  - Photomultiplier
- Thermal detectors
  - Bolometer
  - Thermocouple
  - Pyroelectric
- Weak interaction Detectors
  - Photon drag

Definitions

- Quantum efficiency η: Ratio of the number of electrons collected to the number of photons incident.
- Responsivity: current out divided by optical power incident

$$R_d = \eta \frac{e}{h\nu} = \eta\lambda \frac{e}{hc} = \frac{\eta\lambda}{1.24W / A}$$

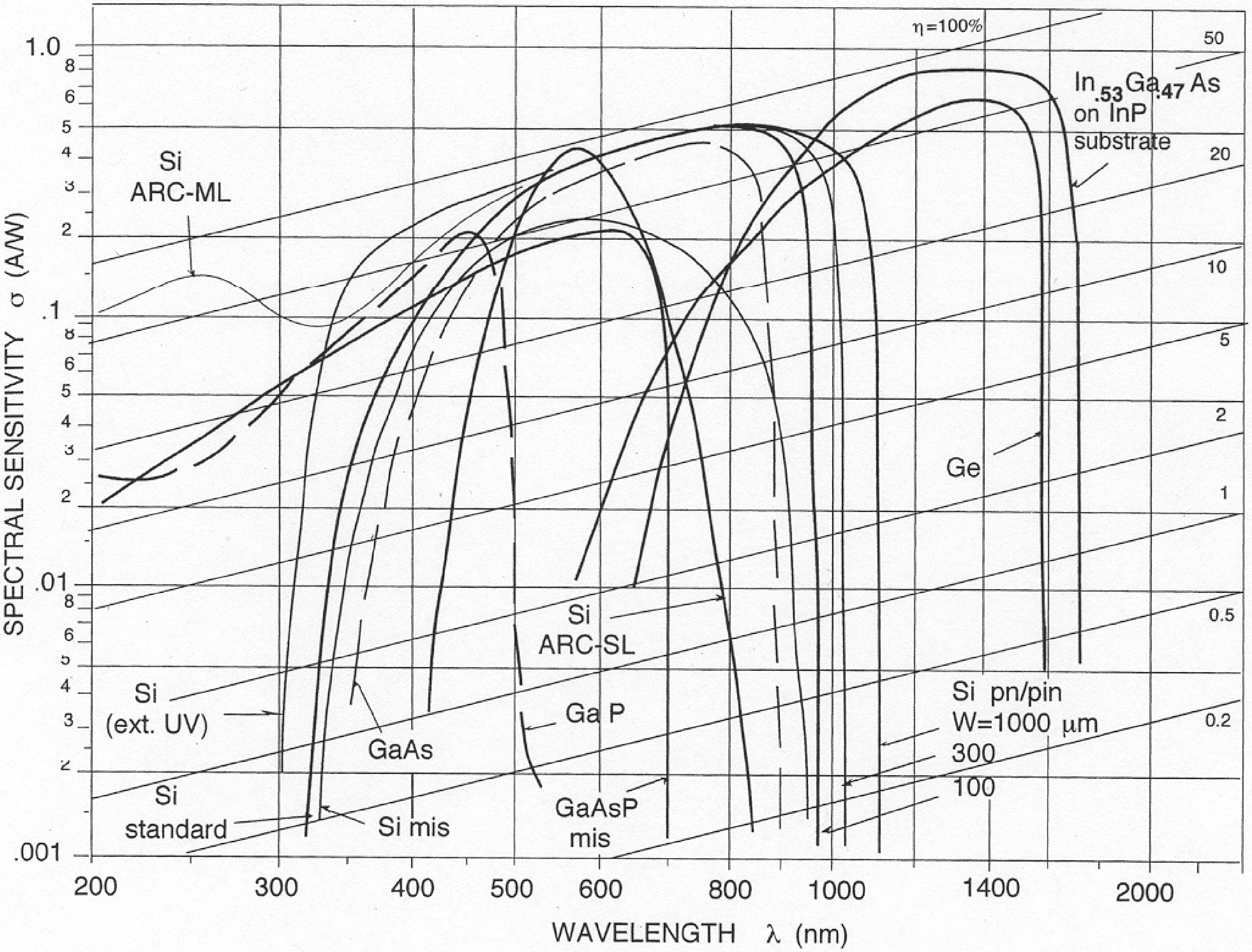


Fig. 5.2.5 Spectral sensitivity $\sigma(\lambda)$ of typical semiconductor photodiodes in several materials and structures from UV to NIR (T=300 K). The lines of equal quantum efficiency η are also indicated.

Absorption

Direct gap in semiconductors: α~1/μm
Indirect gap in semiconductors a~0.01/μm

$$I(z) = I_0 e^{-\alpha z}$$

$$\alpha(\lambda) = K\lambda^2 \sqrt{\frac{hc}{\lambda} - E_G}$$

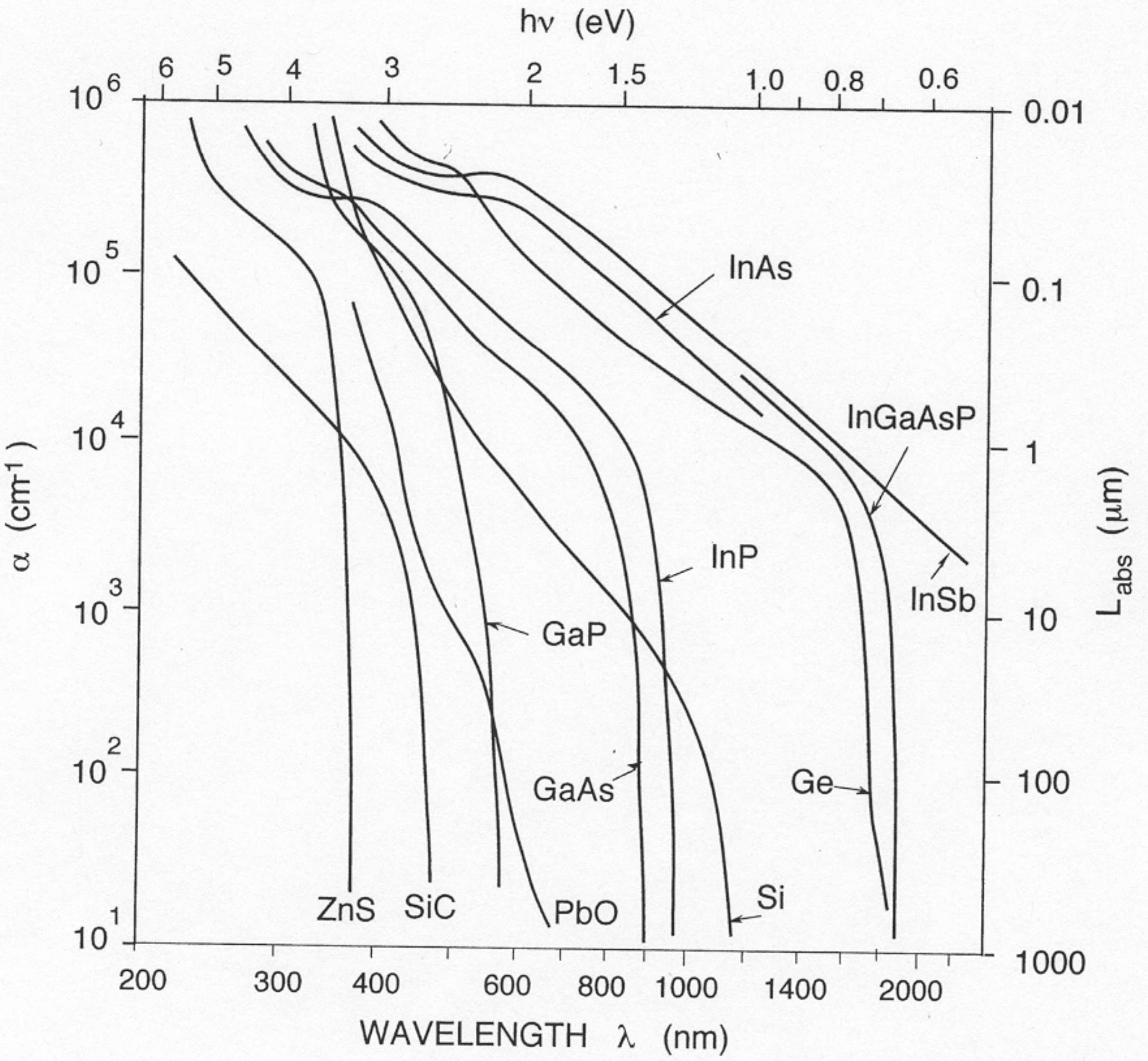


Figure 5-2.2 Wavelength dependence of the absorption coefficient α and of the absorption length L_{abs} for several semiconductors (data for T=300 K)

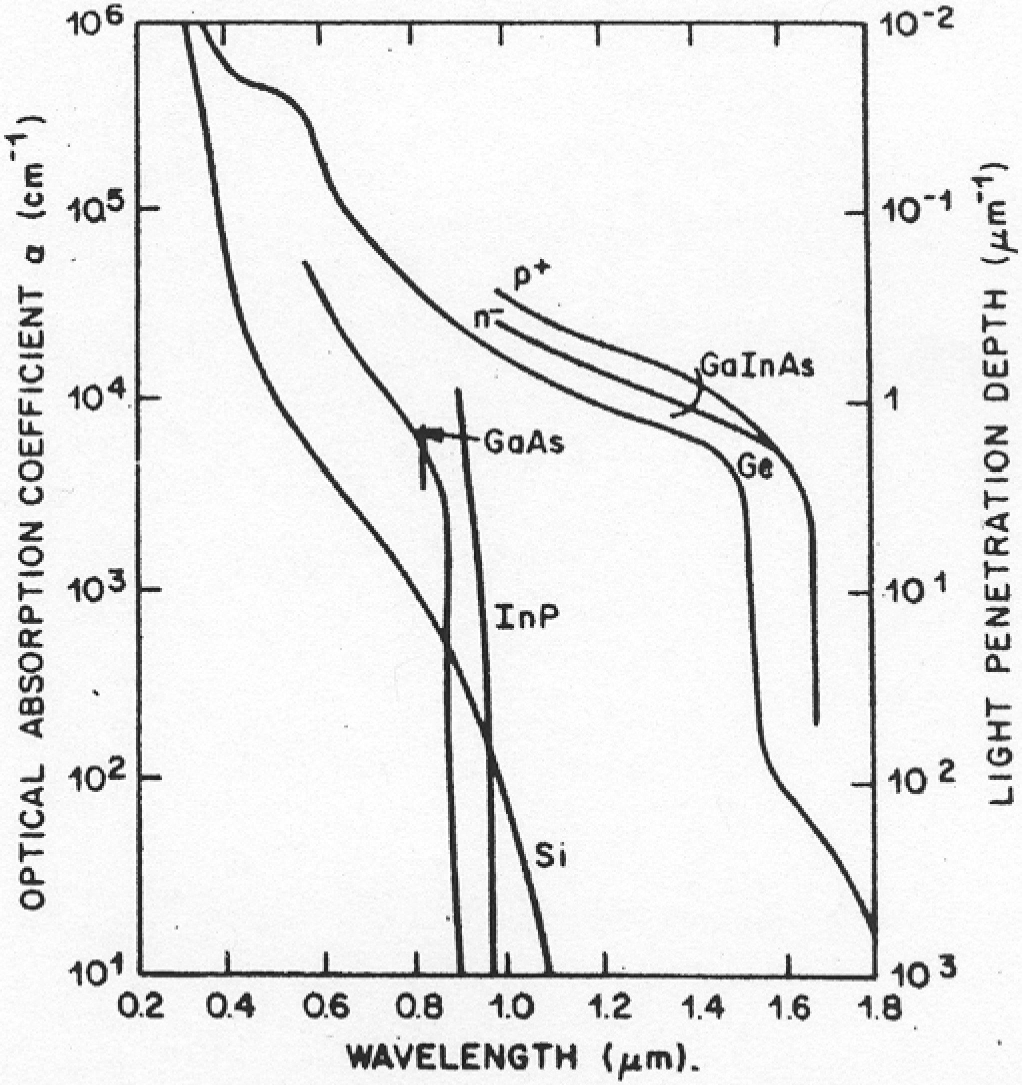
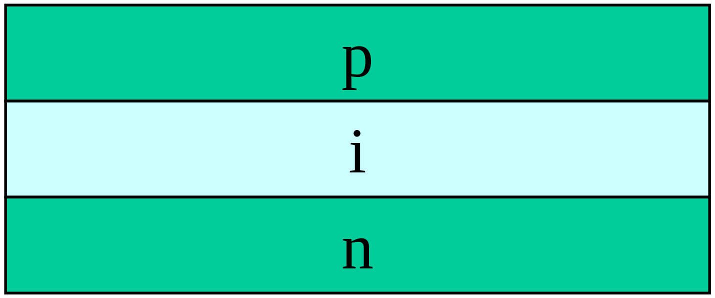


Fig. 6. Dependence of absorption coefficient on wavelength for several materials [18]–[20].

• Photoelectric detectors	Gain?
– Photovoltaic (PIN)	No
– Photoconductive	Yes
– Avalanche photodetector (APD)	Yes
– Phototransistor	Yes


p

i

n

Photodetector Classifications

- Illumination
  - Surface normal
    - Top illuminated
    - Substrate illuminated
  - Surface perpendicular
    - Edge absorbing detectors
    - Waveguide detectors
    - Traveling wave photodetectors
- Contacts
  - Metal (MSM photodetectors)
  - Semiconductor

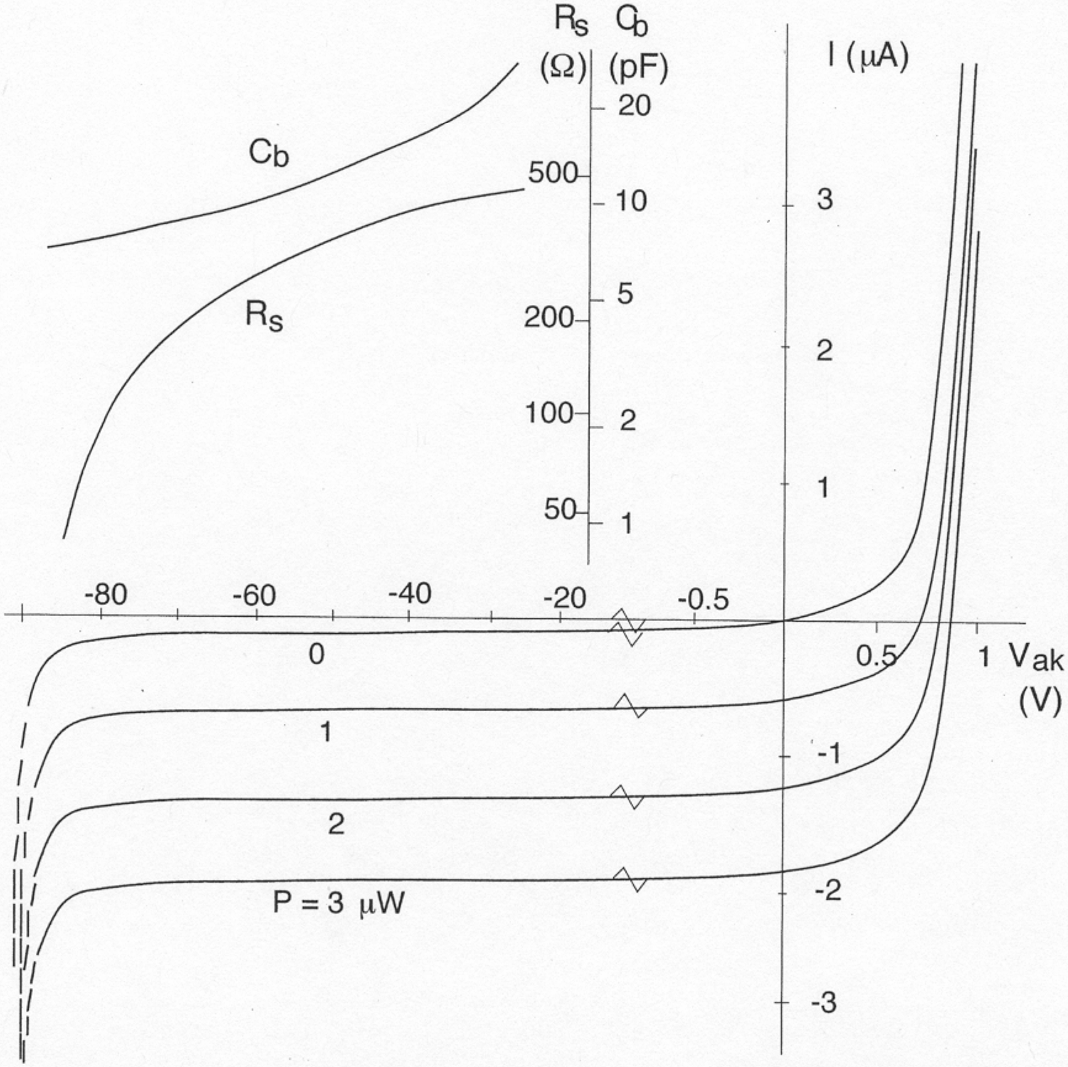


Figure 5-2.7 Current/voltage characteristics of a silicon photodiode (for small signals and λ=900nm). Insert shows the dependence of junction capacitance and series resistance upon V (note the scale change for V<0).

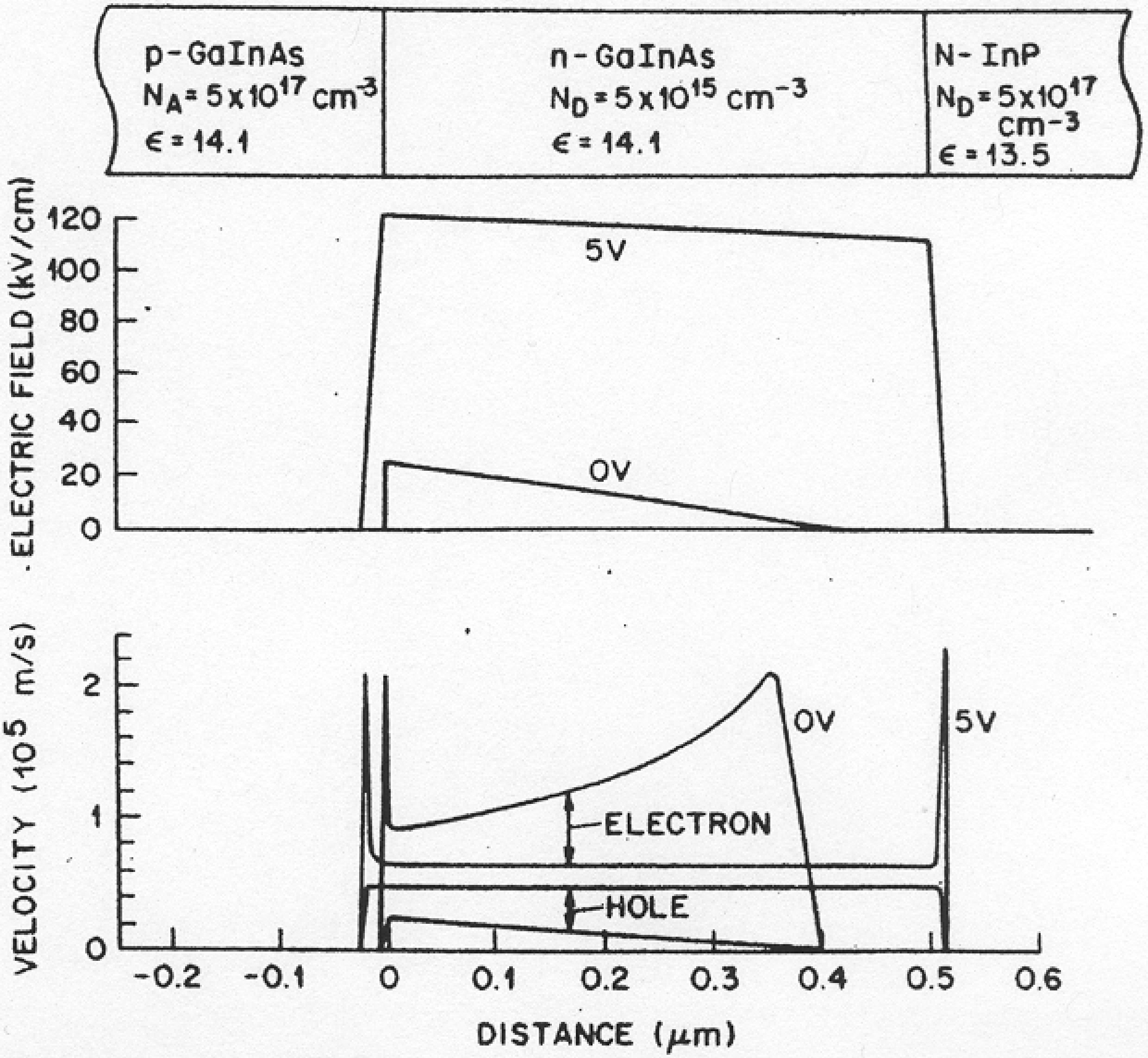


Fig. 2. Schematic diagram of a p-i-n detector and the electric field and electron and hole velocities as a function of position in a p-i-n detector.

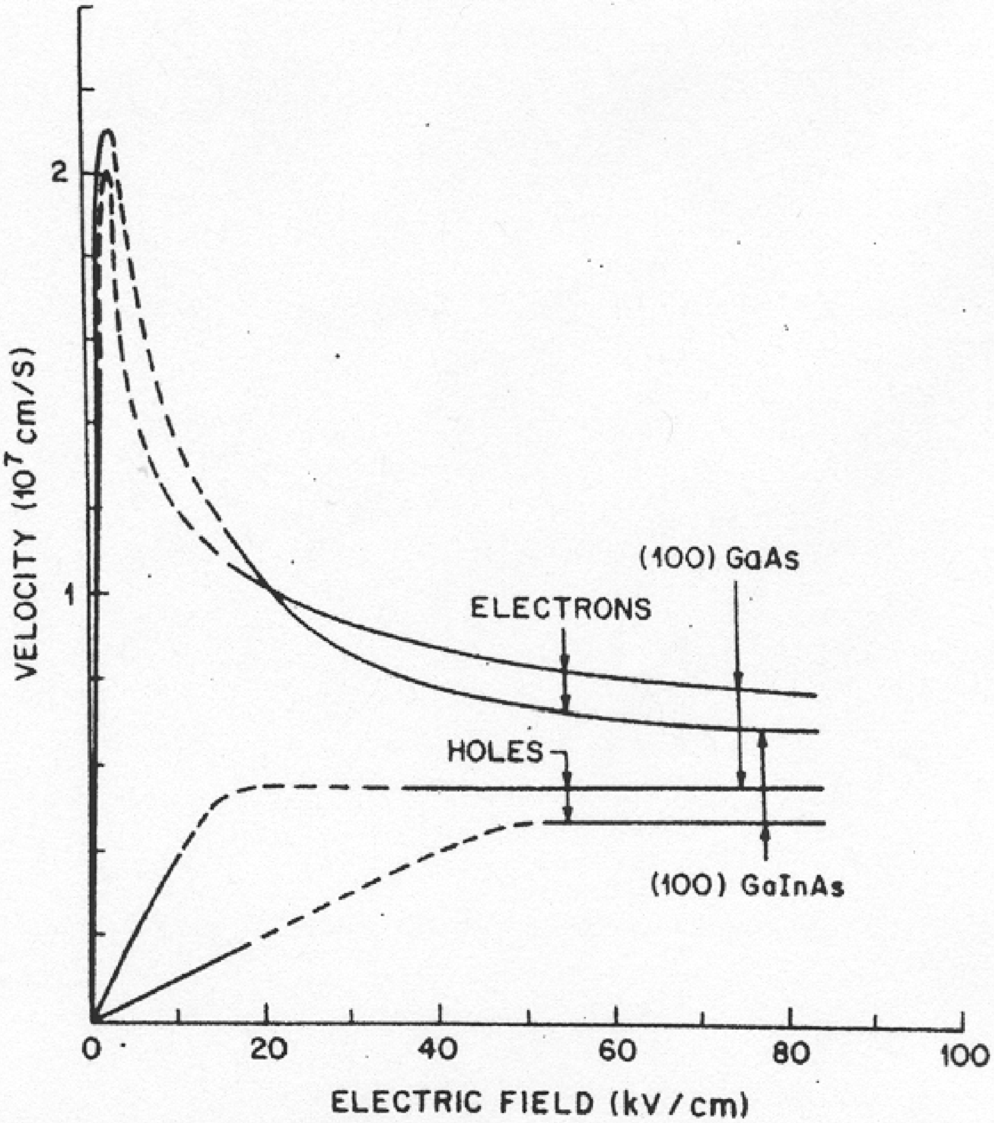


Fig. 1. Dependence of carrier velocity on electric field for GaInAs [11]–[13] and GaAs [14], [15].

PIN Impulse Response?

PIN Impulse Response?

$$j = \frac{v_e e \sigma_e + v_h e \sigma_h}{L}$$

Displacement current flows. That is what is measured in an external circuit, not conduction current.

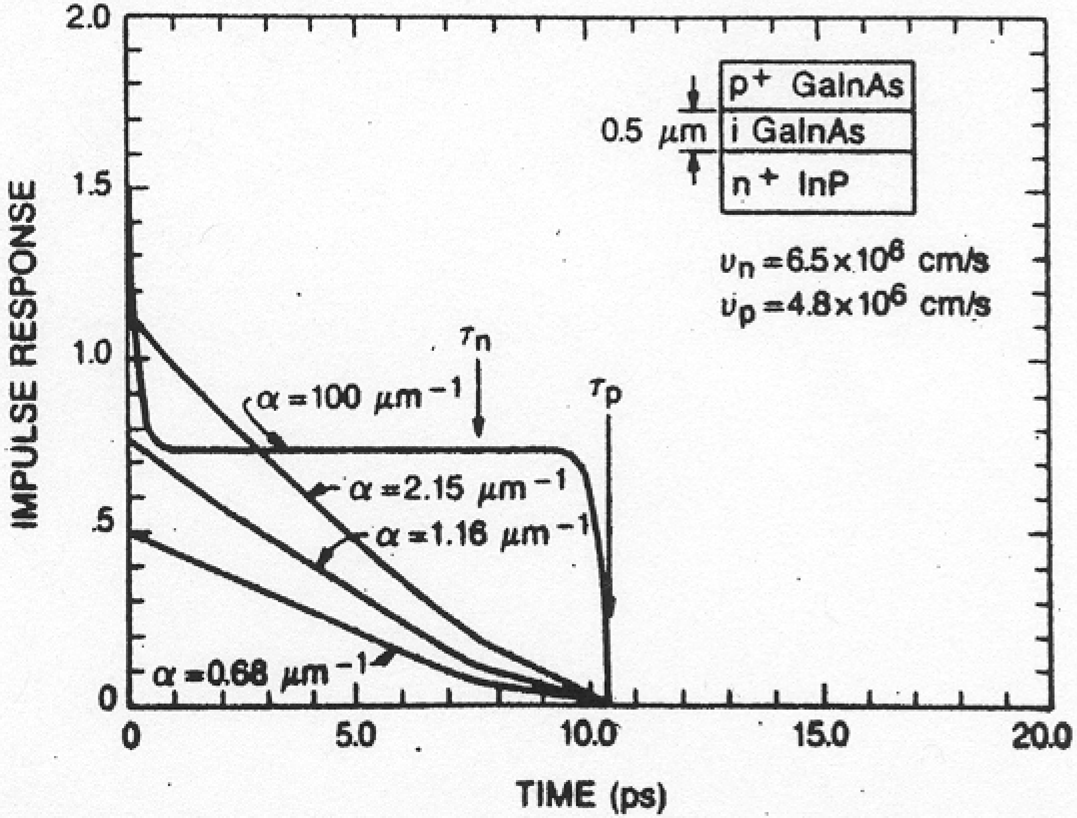


Fig. 3. Impulse response of a p-i-n detector for different values of α: $\alpha = 0.68\ \mu m^{-1}$ ($\lambda = 1.55\ \mu m$), $\alpha = 1.16\ \mu m^{-1}$ ($\lambda = 1.36\ \mu m$), $\alpha = 2.15\ \mu m^{-1}$ ($\lambda = 1.06\ \mu m$), ($v_p = 4.8 \times 10^6$ m/s, $v_n = 6.5 \times 10^6$ m/s, corresponding to GaInAs.

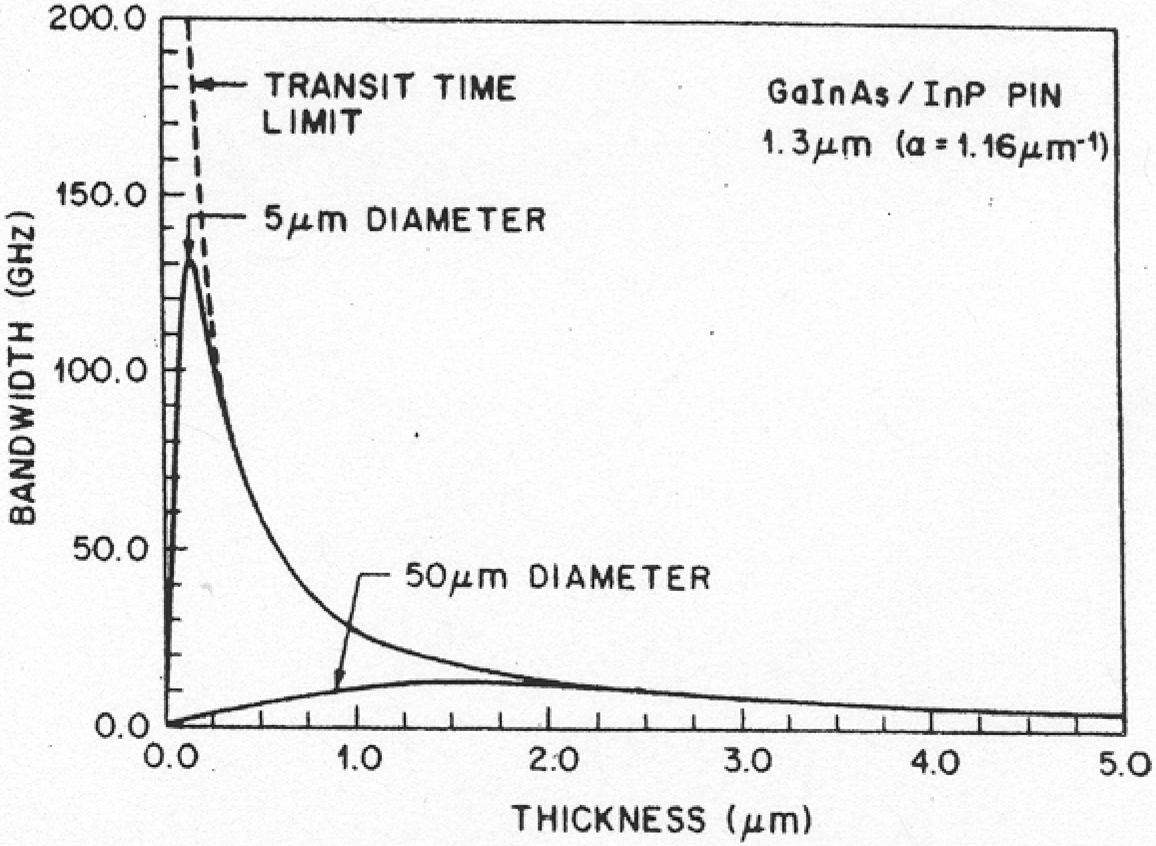


Fig. 4. GaInAs p-i-n detector bandwidth dependence on depletion-layer thickness for 5 and 50 μm diameters. ($\alpha = 1.16$ μm (1.3-μm wavelength) $v_n = 6.5 \times 10^6$ cm/s, $v_p = 4.8 \times 10^6$ cm/s.)