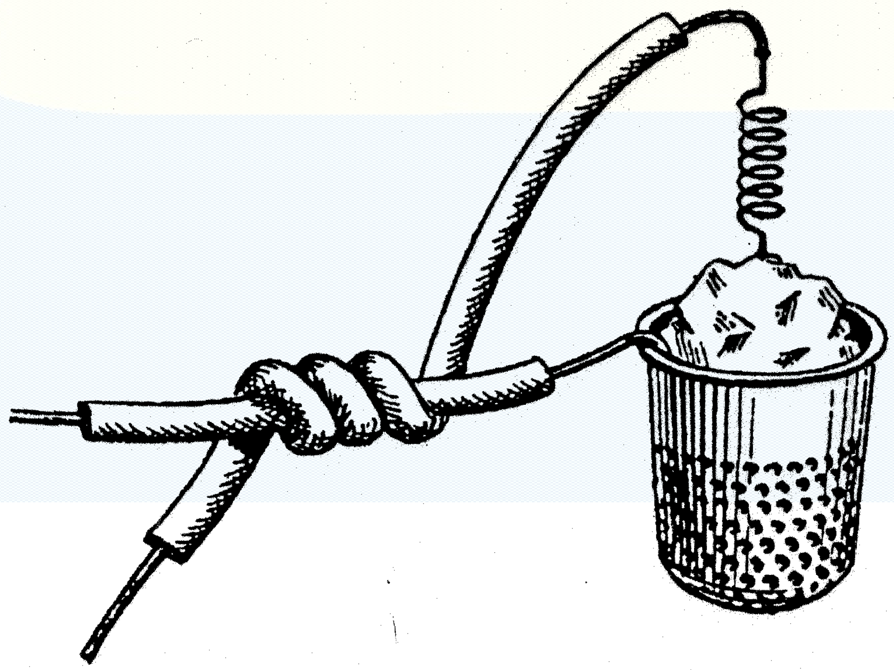
ELECTRONICS
Design Division

Photodetector



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Outline

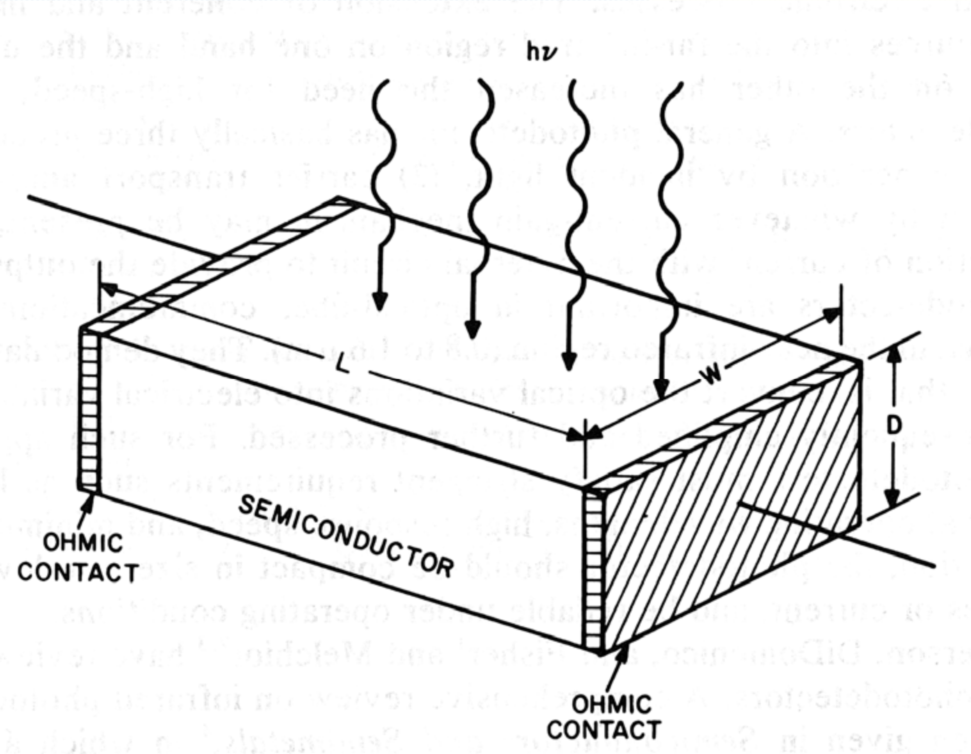
- **Introduction**
- **Photoconductor**
- **Photodiode**
- **Avalanche photodiode**
- **Phototransistor**

Introduction

Detection of photons means, the photons must interact with the detector by three processes:

1) Carrier generation by incident light
2) Carrier transport (with or without carrier multiplication)
3) Interaction of current with external circuit to provide the output signal

Photoconductor

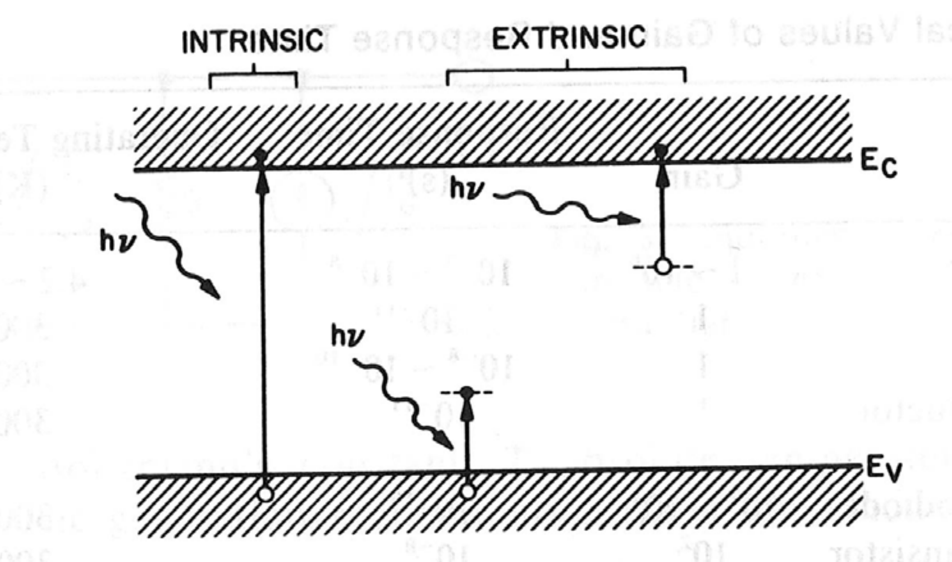


•Slab of semiconductor with ohmic contacts

$$\sigma = q(\mu_n n + \mu_p p)$$

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

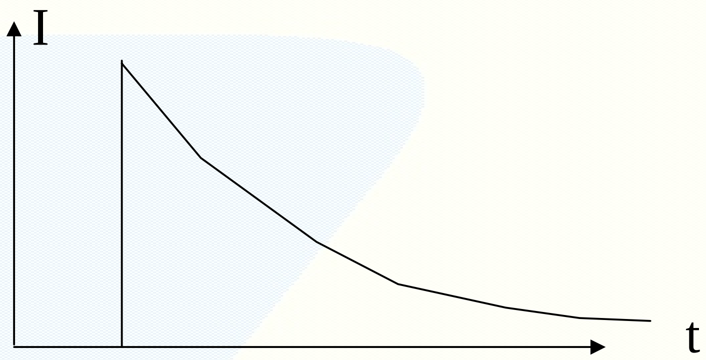
Photoconductor



Recombination of carrier

$$n = n_0 e^{-t/\tau}$$

- τ carrier lifetime



Photoconductor

Generation rate of carrier per unit volume

$$G = \frac{n}{\tau} = \frac{\eta(P_{opt}/h\nu)}{WLD}$$

Photocurrent flowing between contacts

$$I_p = (\sigma\mathscr{E})WD = (q\mu_n n\mathscr{E})WD = (qnv_d)WD$$

$$=$$

$$I_p = q\left(\eta\frac{P_{opt}}{h\nu}\right)\left(\frac{\mu_n\tau\mathscr{E}}{L}\right).$$

Primary photocurrent

$$I_{ph} \equiv q\left(\eta\frac{P_{opt}}{h\nu}\right)$$

Photocurrent gain

$$\text{gain} = \frac{I_p}{I_{ph}} = \frac{\mu_n\tau\mathscr{E}}{L} = \frac{\tau}{t_r}$$

$t_r = L/v_d$ is the carrier transit time.

Photoconductor

Table 1 Typical Values of Gain and Response Time

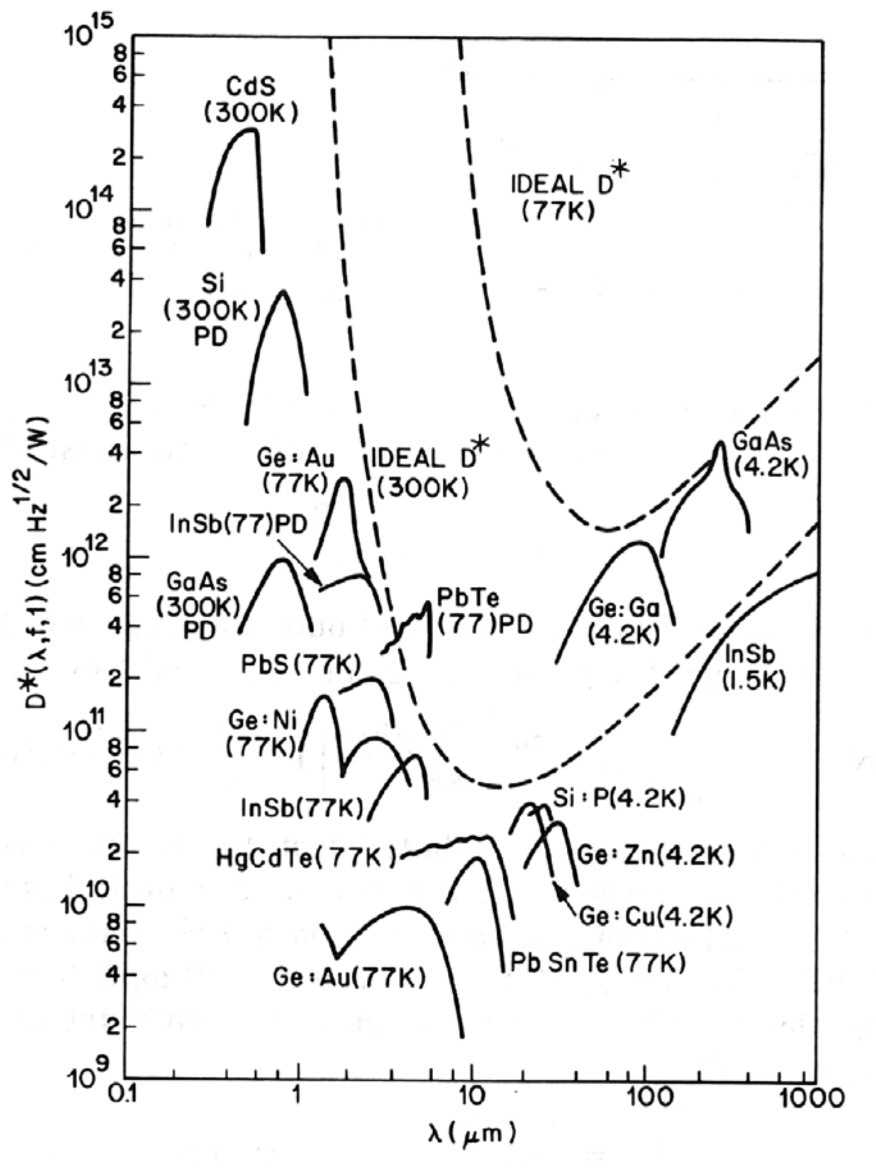
Photodetector	Gain	Response Time (s)	Operating Temperature (K)
Photoconductor	$1 \sim 10^6$	$10^{-3} \sim 10^{-8}$	$4.2 \sim 300$
p-*n* junction	1	10^{-11}	300
p-*i*-*n* junction	1	$10^{-8} \sim 10^{-10}$	300
Metal–semiconductor diode	1	10^{-11}	300
Avalanche photodiode	$10^2 \sim 10^4$	10^{-10}	300
Bipolar phototransistor	10^2	10^{-8}	300
Field-effect phototransistor	10^2	10^{-7}	300

Photoconductor

- Detectivity

$$D^* = \frac{A^{1/2}B^{1/2}}{NEP} \quad \mathrm{cm(Hz)^{1/2}/W.}$$

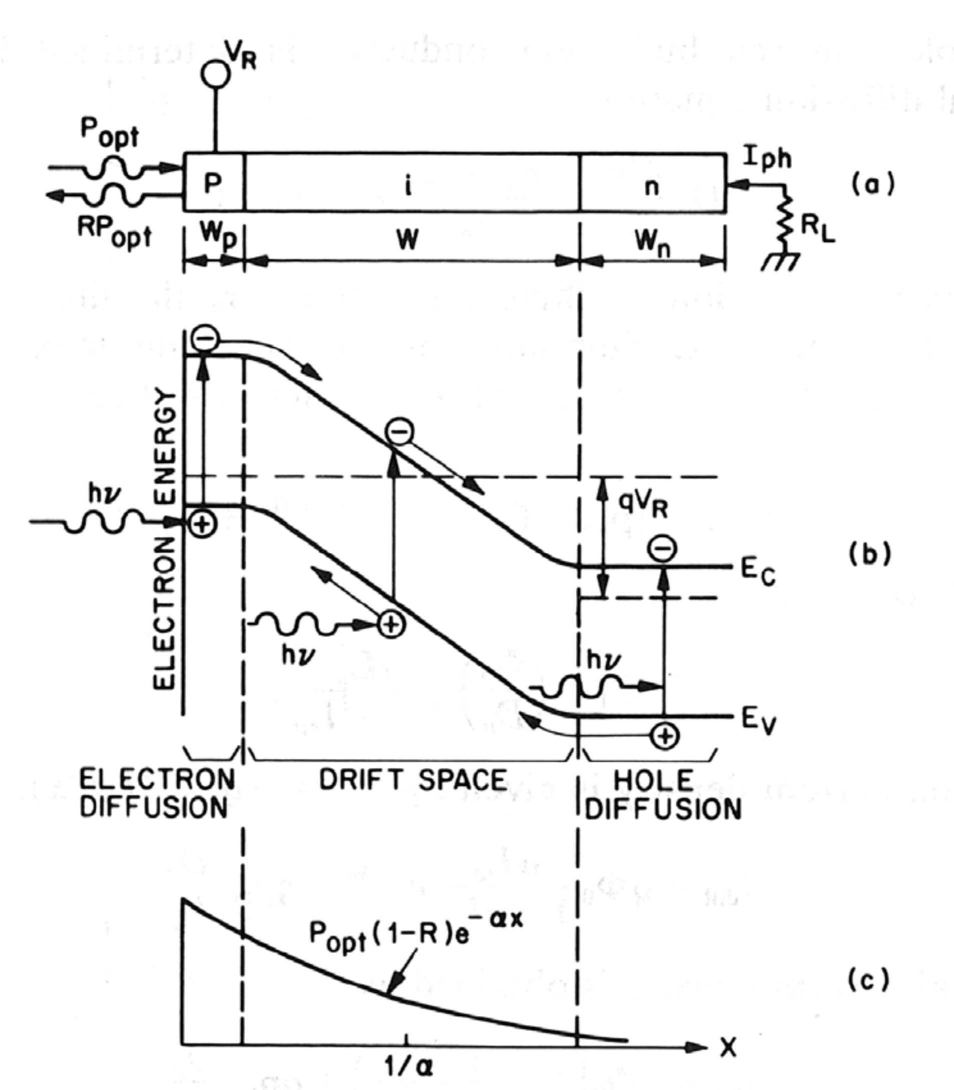
- A=area of detector
- B=bandwidth
- NEP=noise equivalent power



Photodiode

- pn-junction diode
- Metal-semiconductor diode (Schottky diode)
- (Heterojunction diode)

pn-photodiode



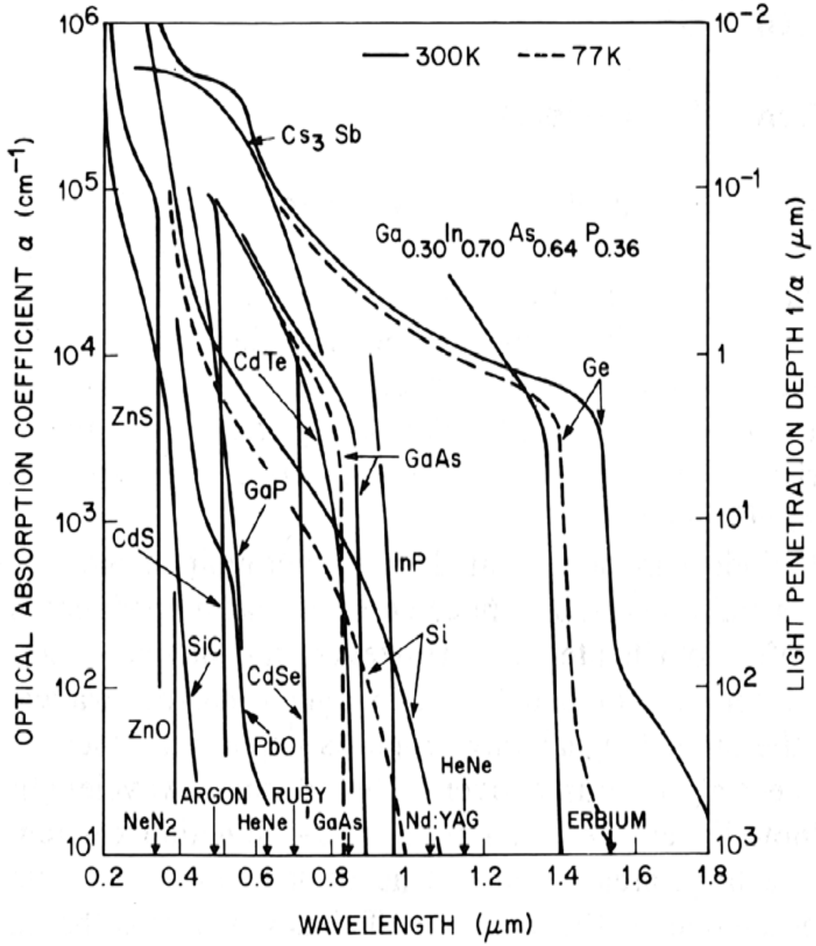
- Responsivity 1
  - –Antireflective coating, minimize reflection
  - –SiO_2-Si interface (if silicon), effect short wavelength responsivity
  - –Effective depth of device (effect long Wavelength responsivity)
- Internal quantum efficiency

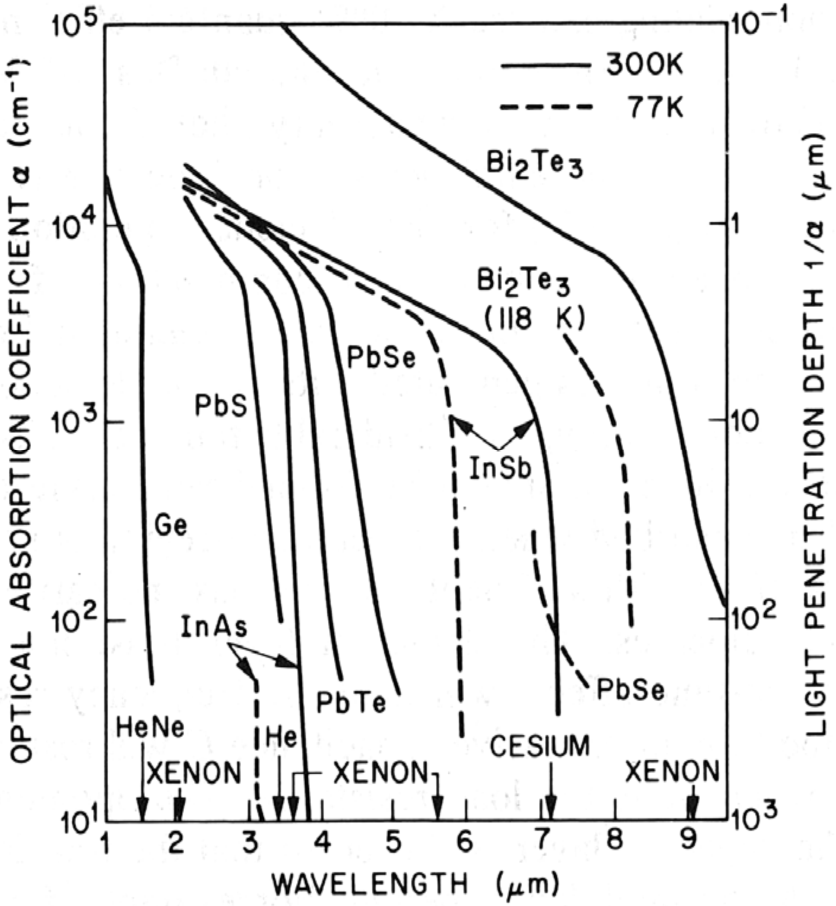
$$\eta = (I_p/q)/(P_{opt}/h\nu)$$

- External quantum effiency
  - –Include optical properties: Reflection, absorption and transmission
- Responsivity 2

$$R = \frac{I_p}{P_{opt}} = \frac{\eta\lambda(\mu m)}{1.24} \quad (A/W)$$

pn-photodiode





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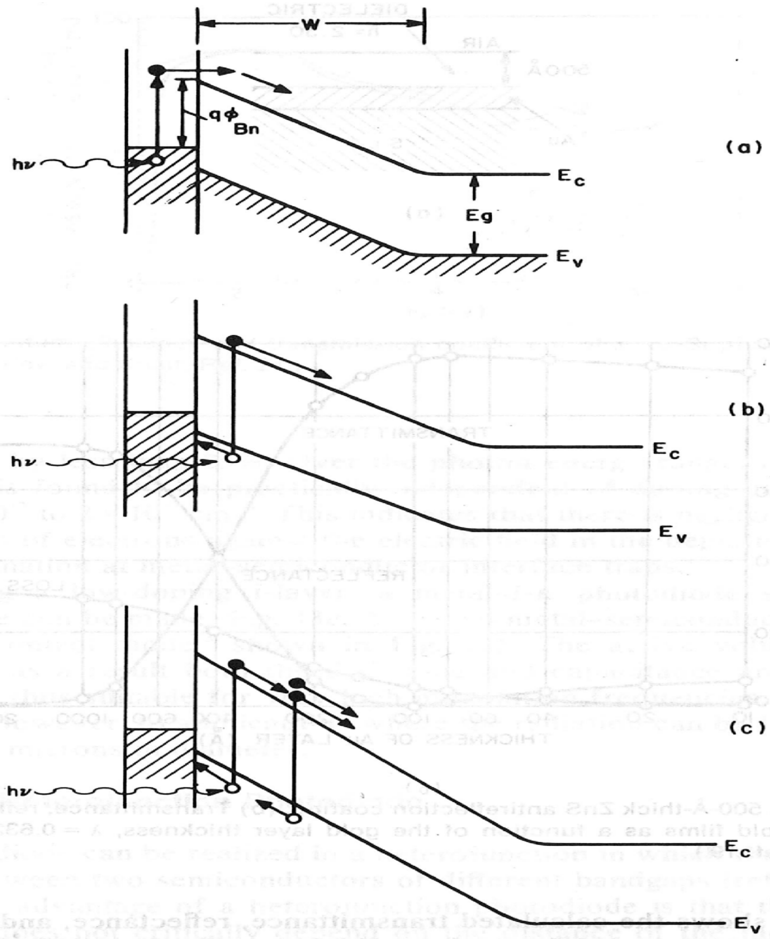
Schottky diode



Thin metal (~100Å) on a semiconductor surface

1 For $E_g > h\nu > q\phi_{Bn}$ and $V < V_B$, Fig. 14*a*, where V_B is the avalanche breakdown voltage, the photoexcited electrons in the metal can surmount the barrier and be collected by the semiconductor. This process has been used extensively to determine the Schottky-barrier height and to study the hot-electron transport in metal films.[20]

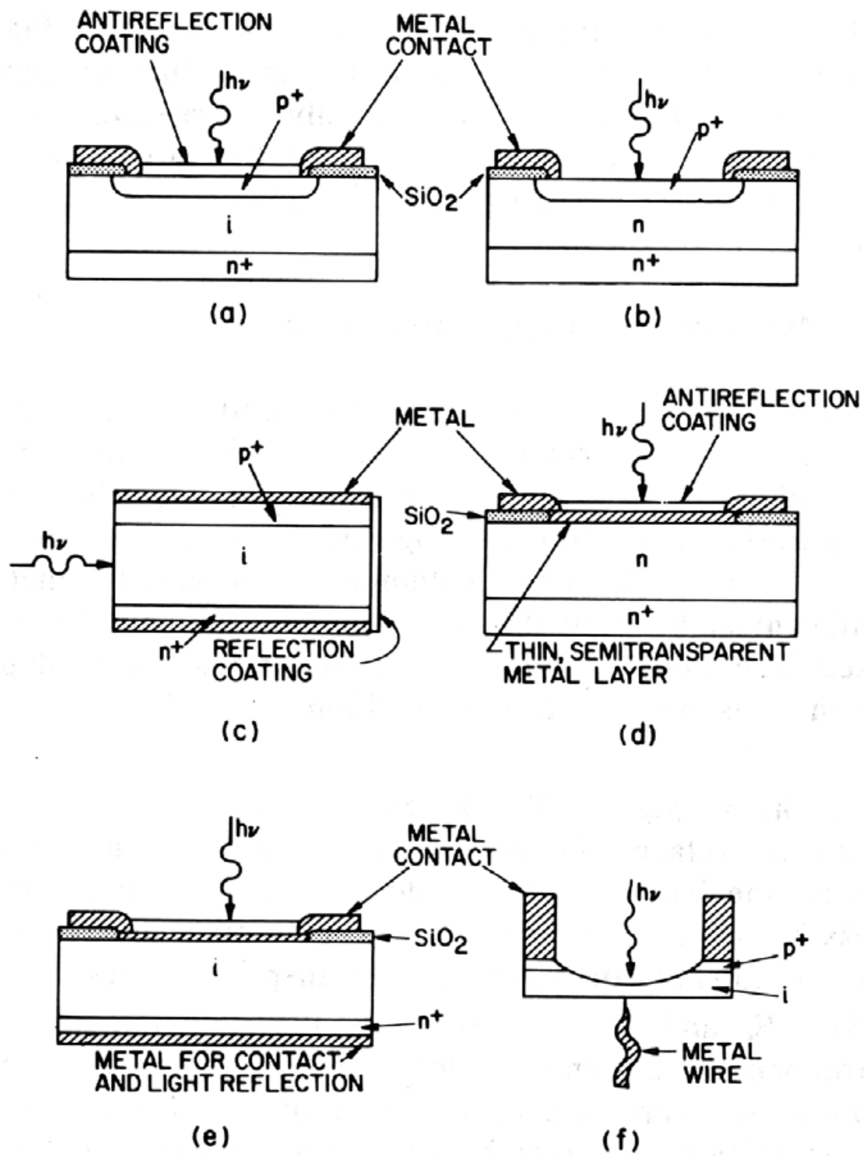
2 For $h\nu > E_g$ and $V < V_B$, Fig. 14*b*, the radiation produces hole–electron pairs in the semiconductor, and the general characteristics of the diode are very similar to those of a *p-i-n* photodiode. The quantum efficiency is given by an expression identical to Eq. 29.

3 For $h\nu > E_g$ and $V \simeq V_B$ (high reverse-bias voltage), Fig. 14*c*, the diode can be operated as an avalanche photodiode (discussed in Section 13.4).

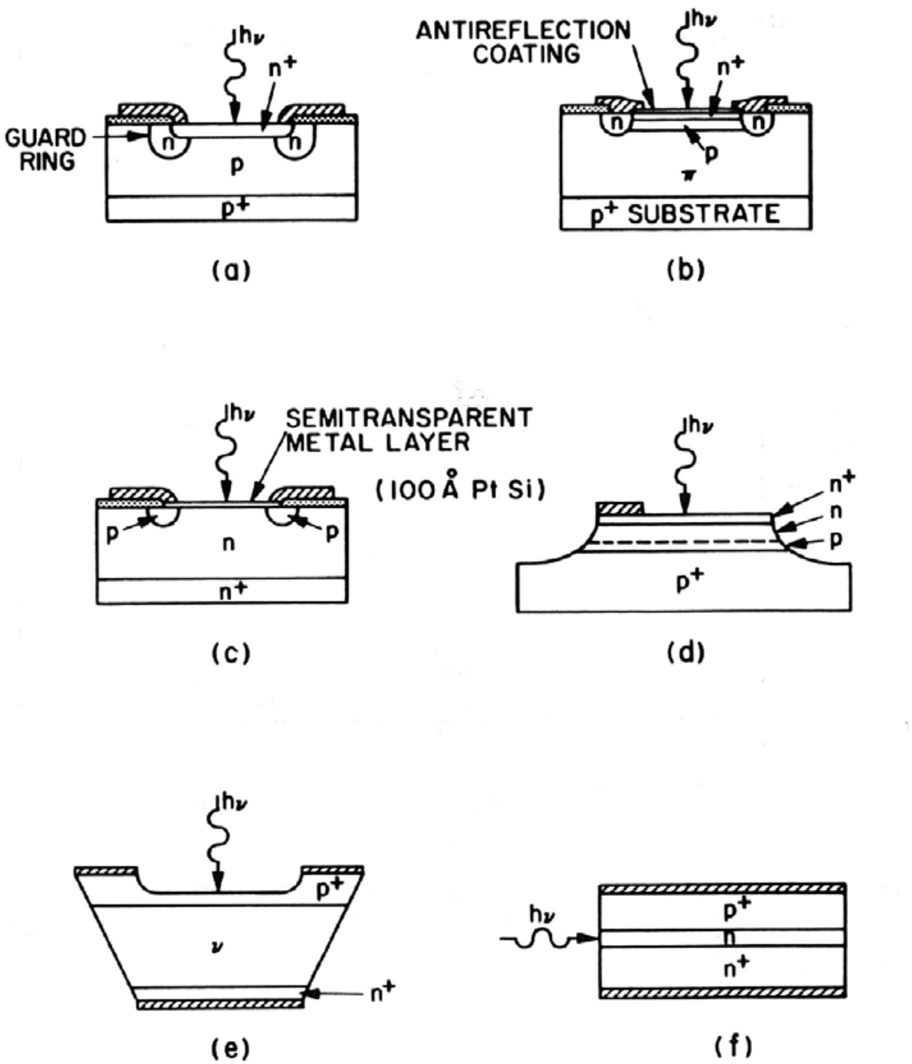
Schottky diode

a,b,c pn-junction

d,e,f schottky-junction



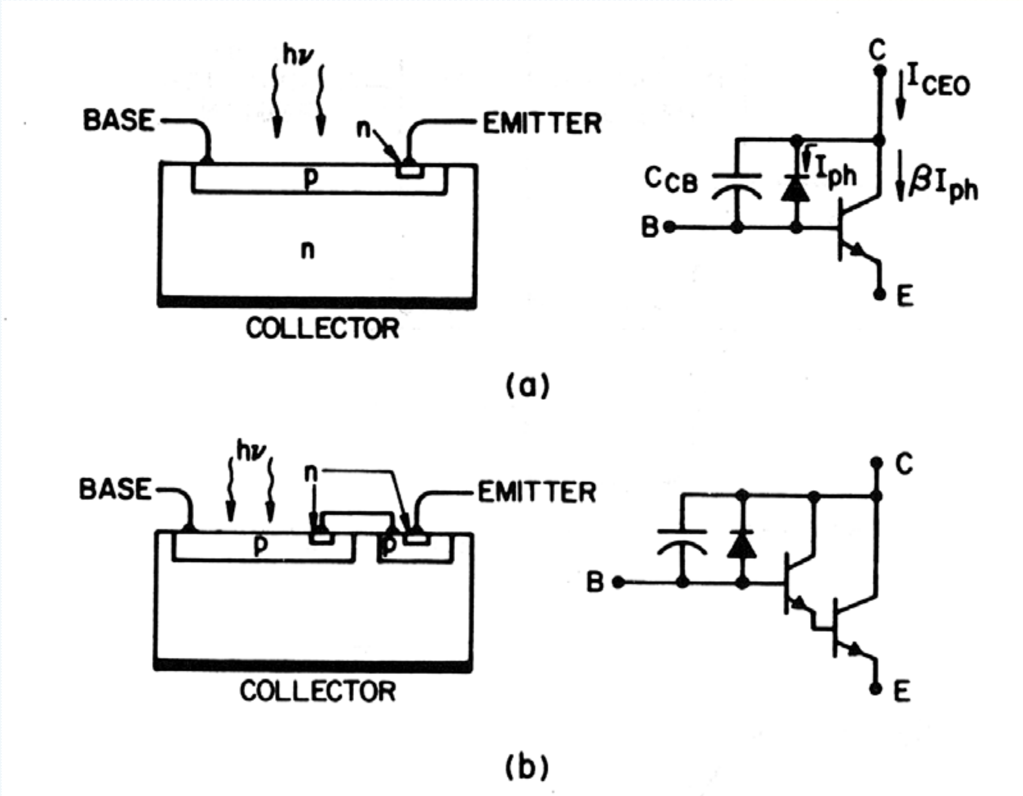
Avalanche photodiode



•Operated at high reverse bias voltage where avalanche multiplication occur.

•Problem to achieve uniform avalanche multiplication in entire light sensitive area

Phototransistor



- High gain through the transistor action
- Slower response-time compared with photodiode
  - –pn-diode 0.01us
  - –Ph-trans. 5 us
  - –Ph darlington 50 us