Chapter 9. PN-junction diodes: Applications

Diode applications:

- Rectifiers
- Switching diodes
- Zener diodes
- Varactor diodes (Varactor = Variable reactance)

Photodiodes

- pn junction photodiodes
- p-i-n and avalanche photodiodes

Solar Cells

Light Emitting Diodes

Lasers

Rectifiers

Low R in forward direction:

– p^+-n-n^+ structure preferred

– The p^+ and n^+ regions reduce the parasitic resistance.

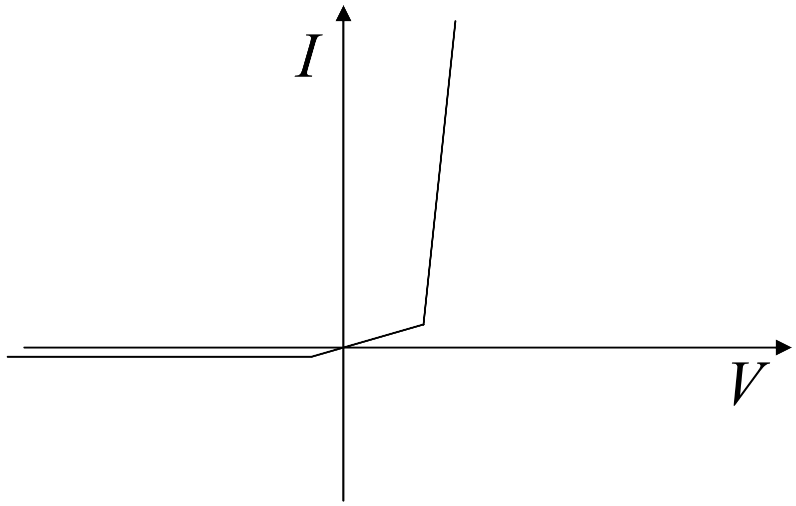
Low I_0 in reverse:

– Ge is worse than Si. Why?

High voltage breakdown in reverse:

– p^+-n-n^+ structure

– Higher bandgap materials preferred. Why?



Switching diodes

- Diodes can be used as switching devices
- Need to change from conducting to non-conducting at high speed
- Storage time or turn-off transients should be small
- Add recombination centers to reduce minority carrier lifetimes

  For example adding $10^{15}cm^{-3}$ gold (Au) to Si reduces hole lifetime to 0.01 μs from 1 μs!

- Use narrow-base diodes

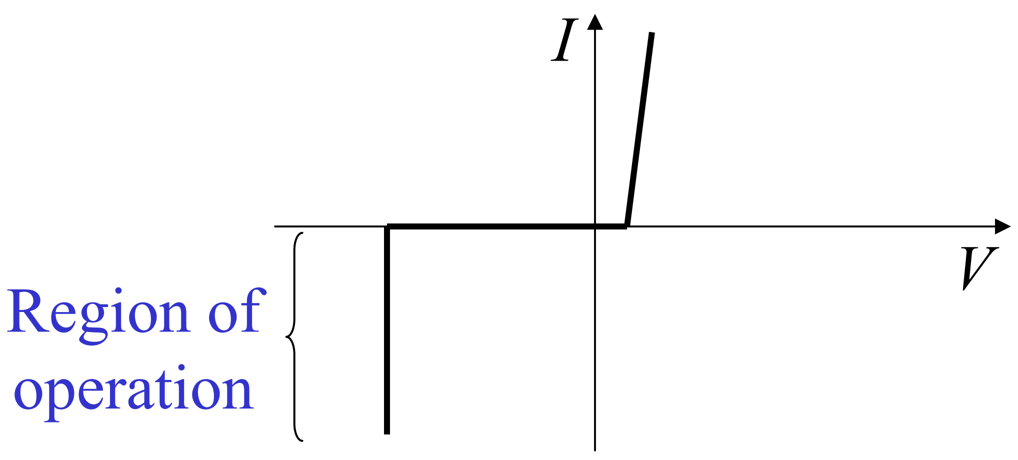
  Amount of charge stored in the neutral region of the diode will be small.

Zener diodes

The breakdown characteristics of diodes can be tailored by controlling the doping concentration

Heavily doped p^+ and n^+ regions result in low breakdown voltage (Zener effect)

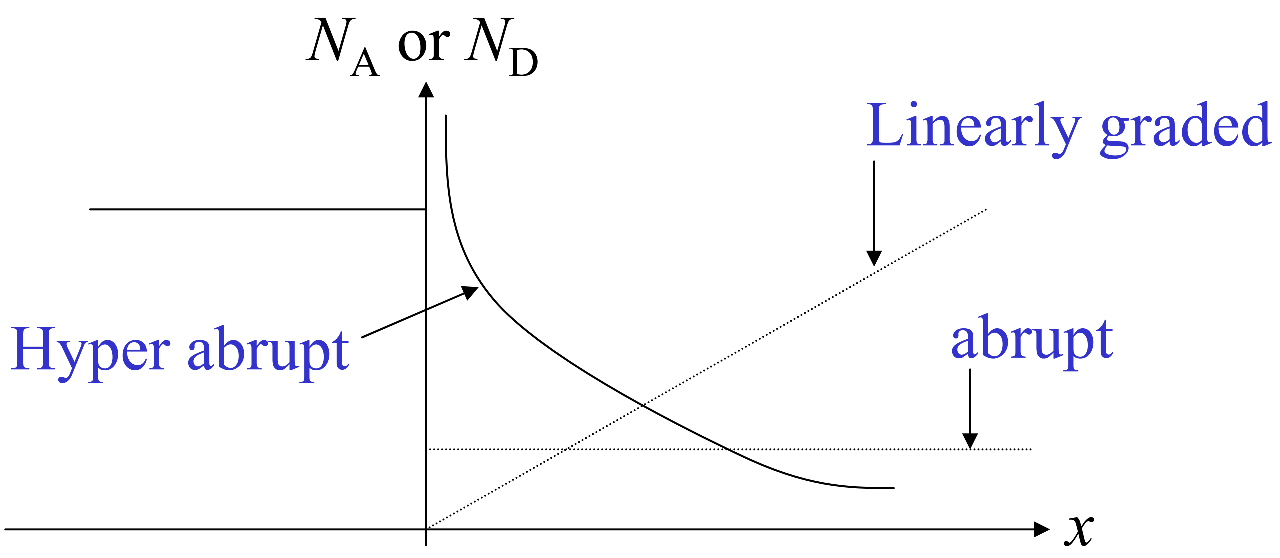
Used as reference voltage in voltage regulators



Varactor diodes (Variable reactance diode)

Voltage-controlled capacitance of a pn junction can be used in tuning stage of a radio or TV receiver.

$C_J \propto (V_A)^{-n}$, where n = 1/2 for an abrupt pn junction. However, n can be made higher than 1/2 by suitably changing the doping profile.



Opto-electronic diodes

Many of these diodes involve semiconductors other than Si. Use *direct* bandgap semiconductors.

Devices to convert optical energy to electrical energy

- photodetectors: generate electrical signal
- Solar cells: generate electrical power

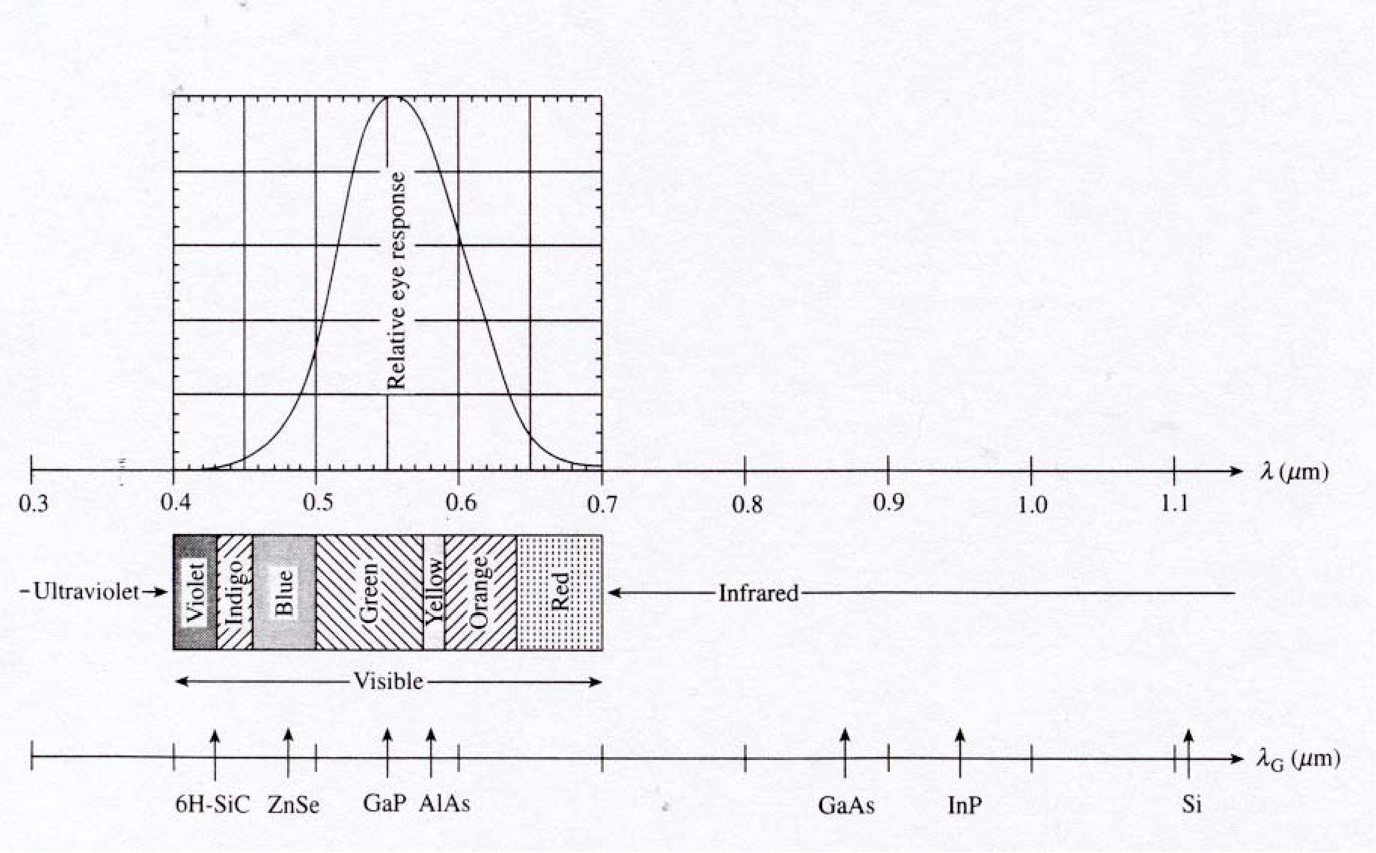
Devices to convert electrical energy to optical energy

- light emitting diodes (LEDs)
- laser diodes

Optical spectrum correlated with relative eye sensitivity

Photon energy $E_{ph} = h\,c\,/\,\lambda$

Inserting numerical values for h and c yields $E_{ph} = 1.24\ \mathrm{eV}\ \mu\mathrm{m}\,/\,\lambda$



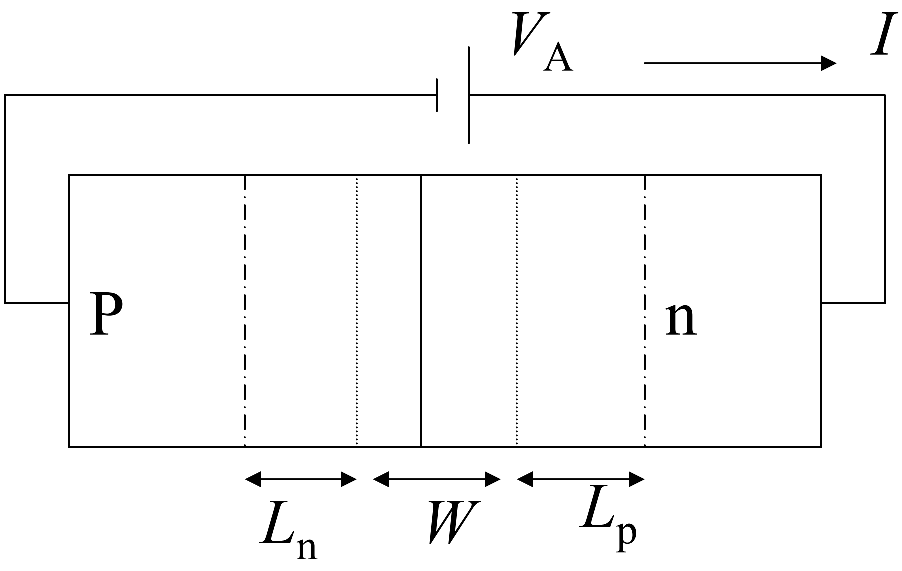
Note: Our eye is very sensitive to green light

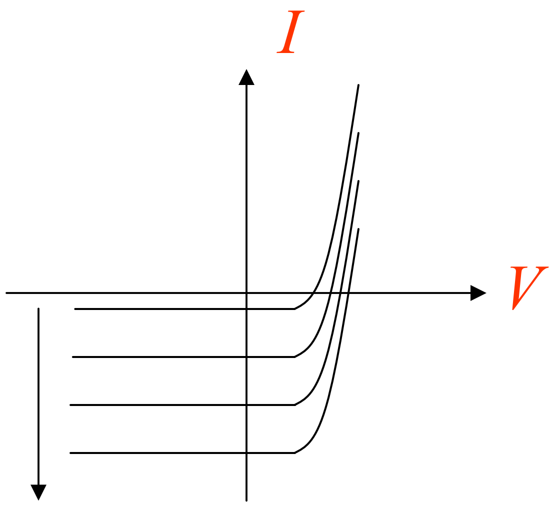
Photodiodes

Specifically designed for detector application and light penetration

$I_L = -q\,A\,(L_N + W + L_P)\,G_L$ assuming uniform photo-generation rate, G_L

$I = I_{dark} + I_L$





Photodiodes

If the depletion width is negligible compared to $L_n + L_p$, then I_L is proportional to light intensity.

Spectral response - an important characteristic of any photo-detector. Measures how the photocurrent, I_L varies with the wavelength of incident light.

Frequency response - measures how rapidly the detector can respond to a time varying optical signal. The generated minority carriers have to diffuse to the depletion region before an electrical current can be observed externally. Since diffusion is a slow process, the maximum frequency response is a few tens of MHz for pn junctions. Higher frequency response (a few GHz) can be achieved using p-i-n diodes.

p-i-n photodiodes

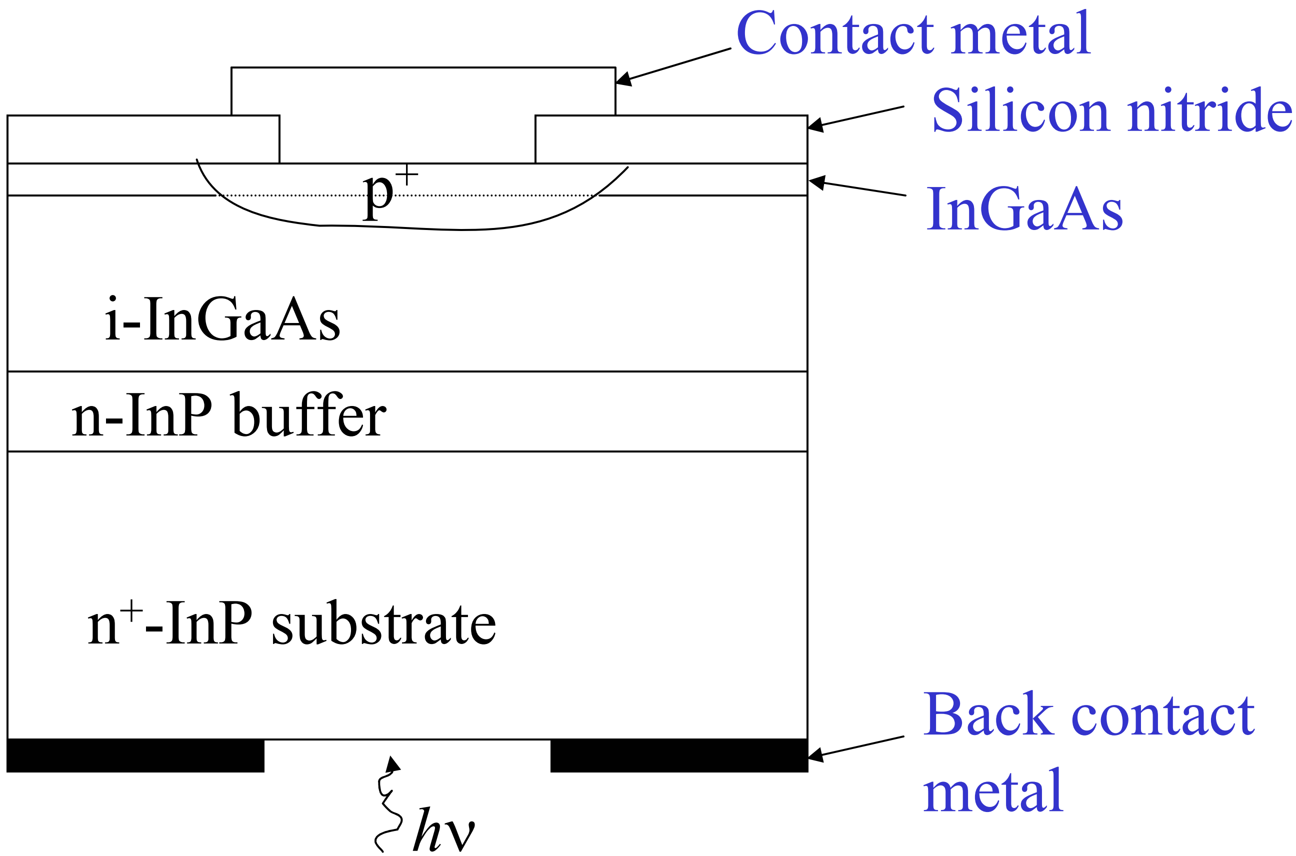
The **i-region** is very lightly doped (it is effectively **intrinsic**). The diode is designed such that most of the light is absorbed in the i-region. Under small reverse bias, the i-region is depleted, and the carriers generated in the i-region are collected rapidly due to the strong electric field. If W_i is the thickness of i-region,

$$f_{max} = \frac{1}{\text{carrier transit time across } W_i} \approx \frac{1}{(W_i / v_{sat})}$$

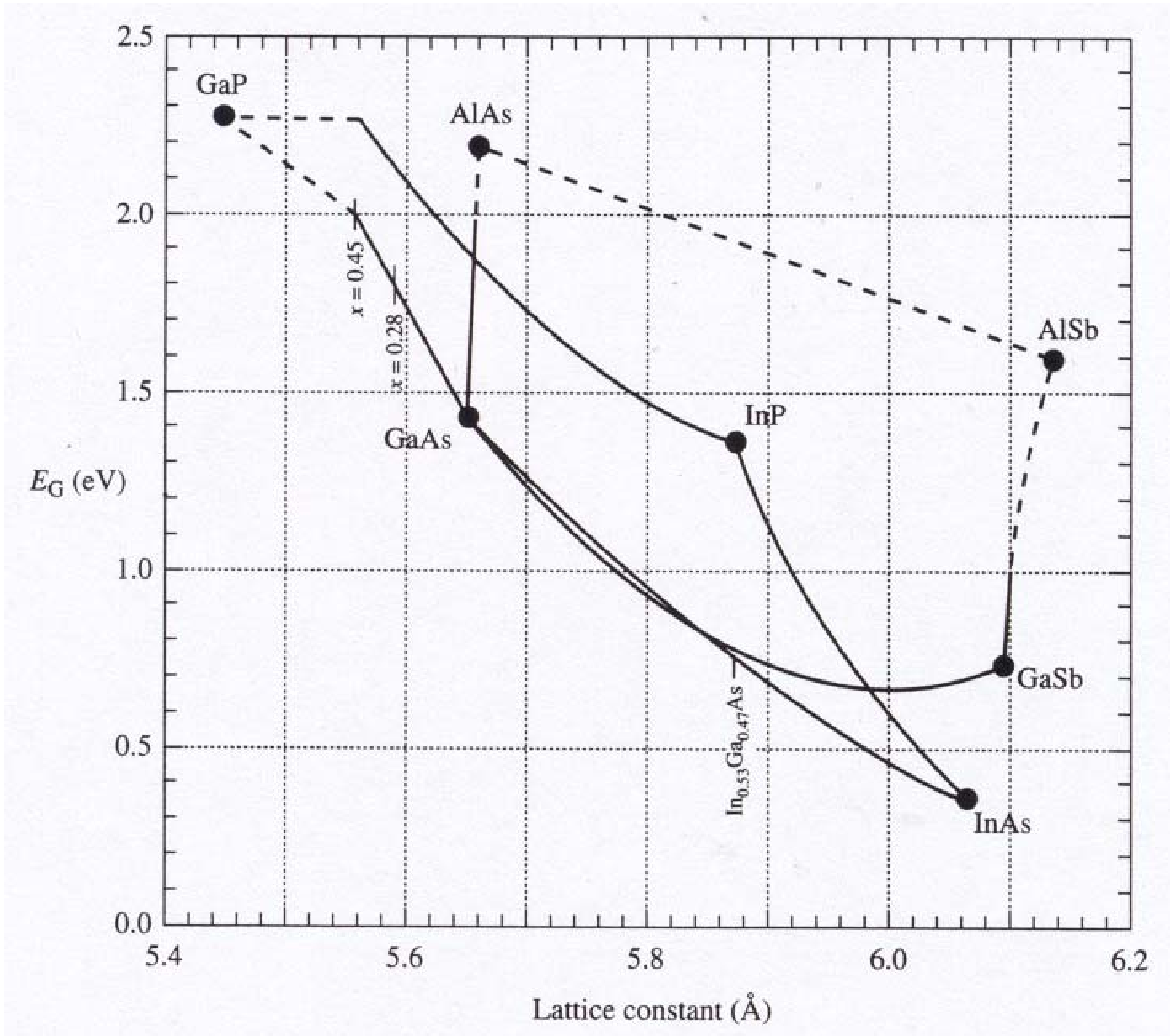
If $W_i = 5$ μm, $v_{sat} = 10^7$ cm/s, then $f_{max} = 20$ GHz. P-i-n diodes operating at 1.3 μm and 1.55 μm are used extensively in optical fiber communications.

p-i-n photodiodes

p-i-n photodiodes operating at 1.55 μm are made on $In_{0.53}Ga_{0.47}As$ deposited on InP substrate.

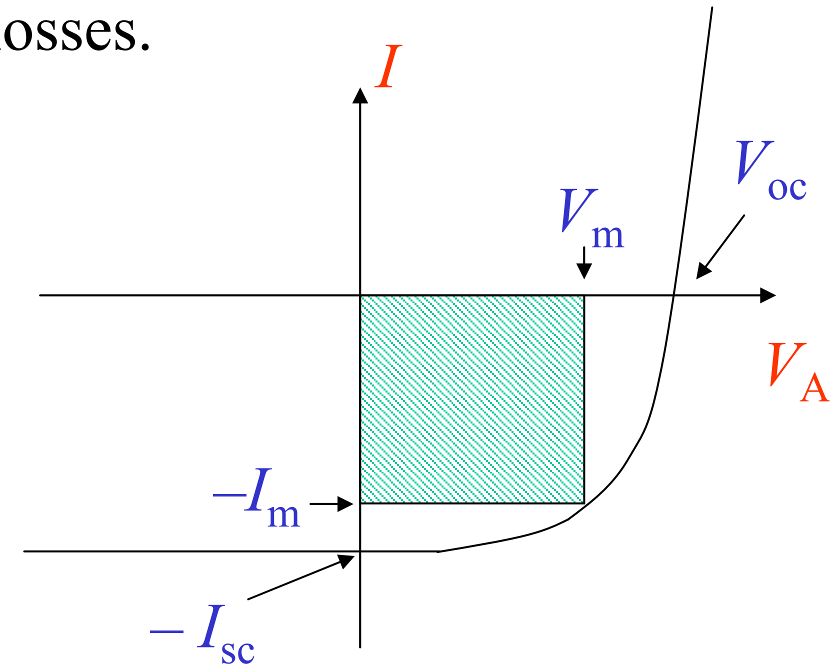


Bandgap energy versus lattice constant of selected III-V compounds and alloys



Solar cells

Solar cells are large area pn-junction diodes designed specifically to avoid energy losses.

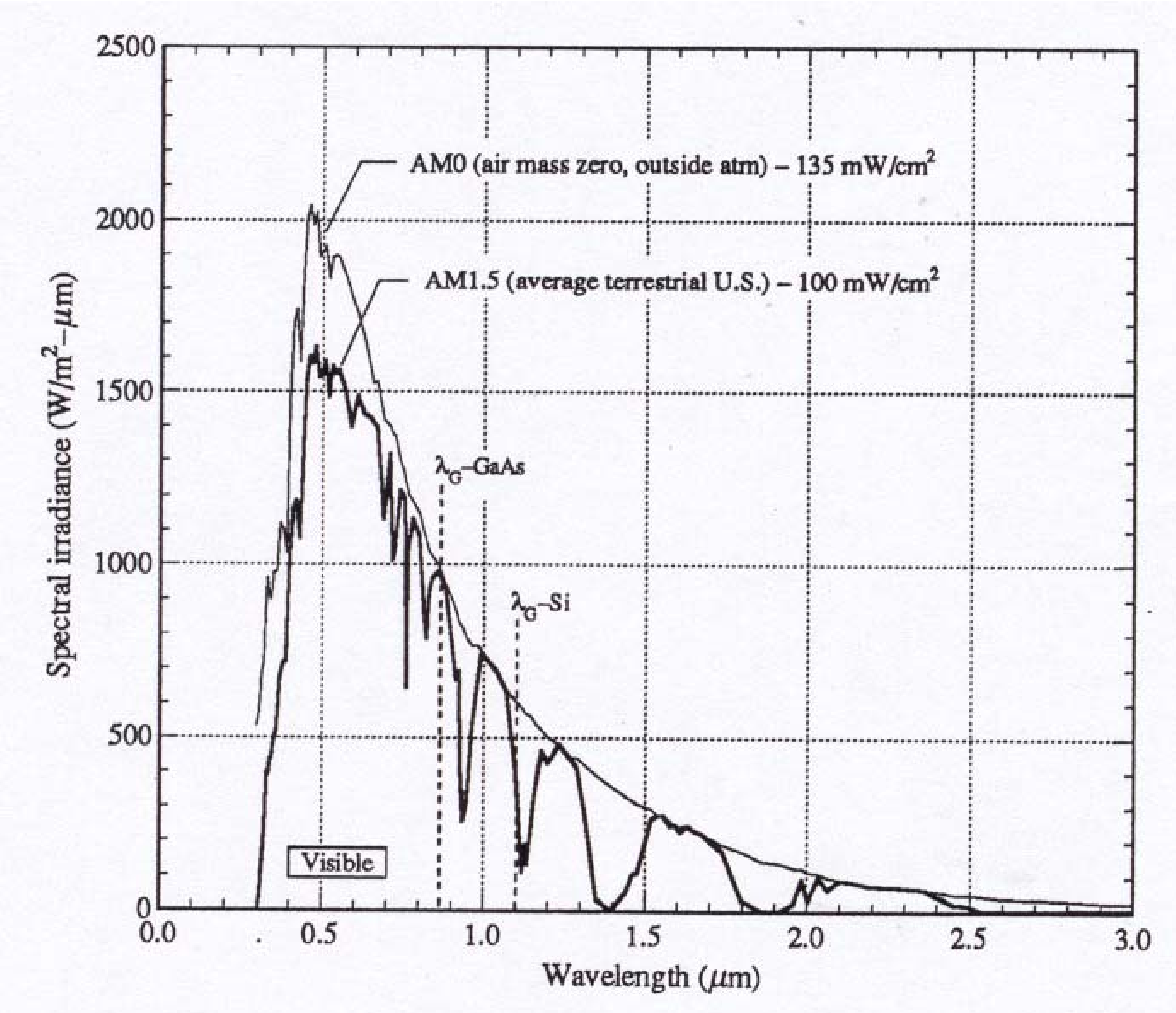


V_{oc} = the open circuit voltage

I_{sc} = current when device is short circuited

η = power conversion efficiency = $(I_m V_m)/P_{in}$

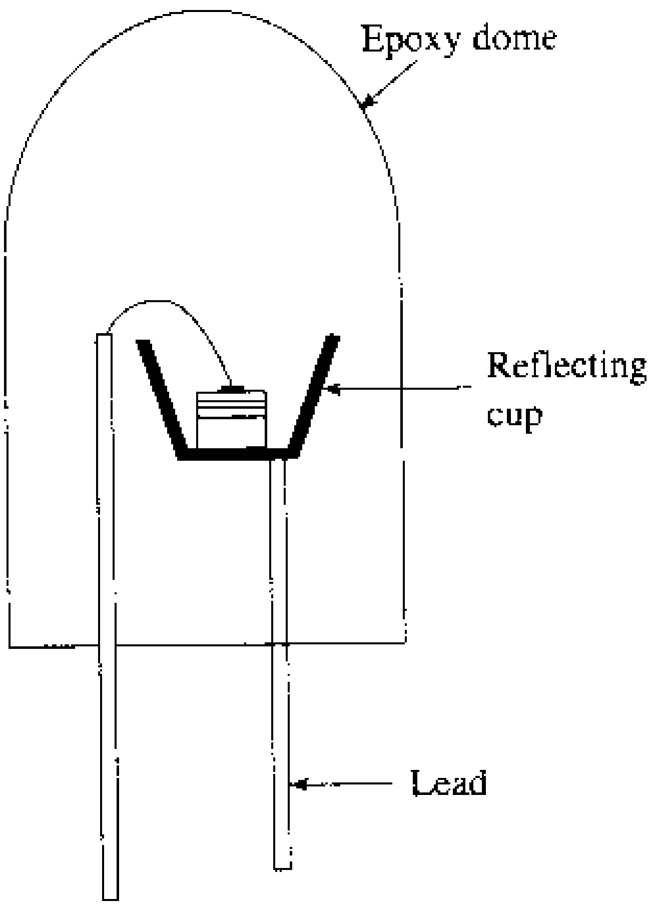
Solar spectral irradiance



Light-emitting diodes

When pn junction is forward biased, large number of carriers are injected across the junctions. These carriers recombine and emit light if the semiconductor has a direct bandgap.

For visible light output, the bandgap should be between 1.8 and 3.1 eV.



Characteristics of commercial LEDs

Semiconductor	*Color*	*Peak $\lambda(\mu m)$*	*External Efficiency η (%)*	*Performance (lumens/watt)*†
		Established Materials		
$GaAs_{0.6}P_{0.4}$	Red	0.650	0.2	0.15
$GaAs_{0.35}P_{0.65}$:N	Orange-Red	0.630	0.7	1
$GaAs_{0.14}P_{0.86}$:N	Yellow	0.585	0.2	1
GaP:N	Green	0.565	0.4	2.5
GaP:Zn-O	Red	0.700	2	0.40
		Recent Additions		
AlGaAs	Red	0.650	4–16	2–8
AlInGaP	Orange	0.620	6	20
AlInGaP	Yellow	0.585	5	20
AlInGaP	Green	0.570	1	6
SiC	Blue	0.470	0.02	0.04
GaN	Blue	0.450	2	0.6

LED cross section