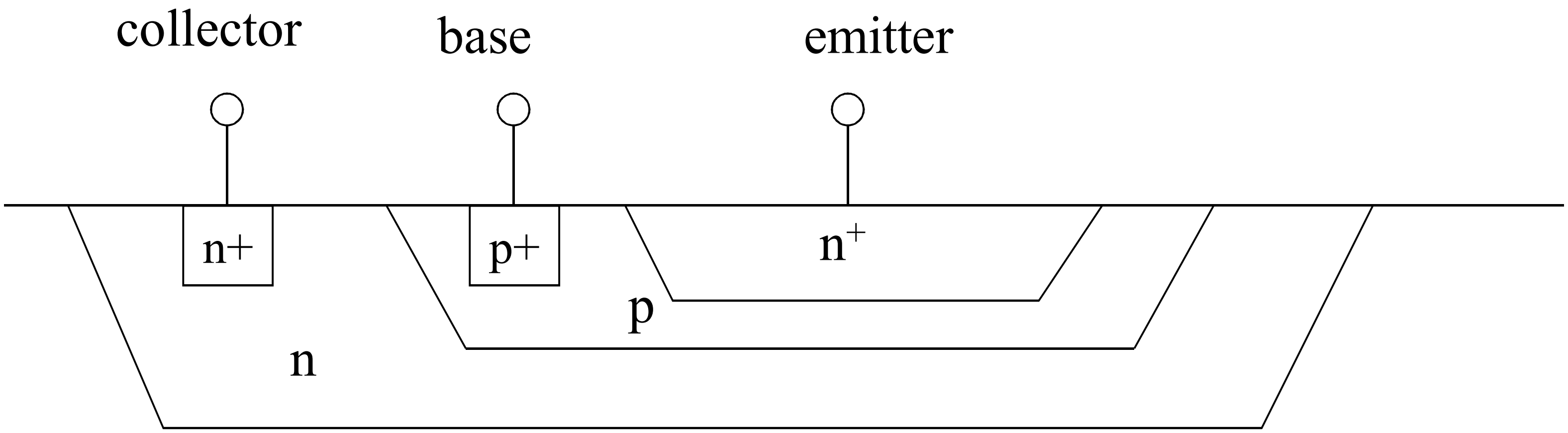
Bipolar transistors, Thyristors, and Latch-up

bipolar transistors

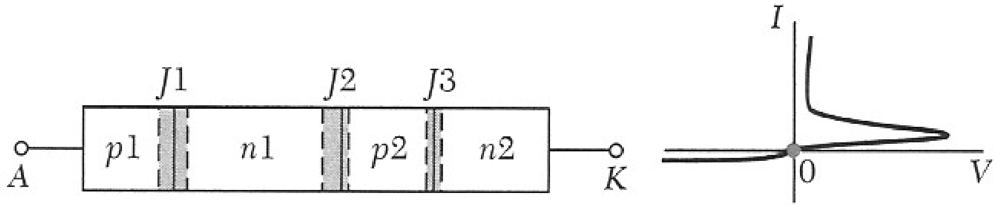
npn transistor



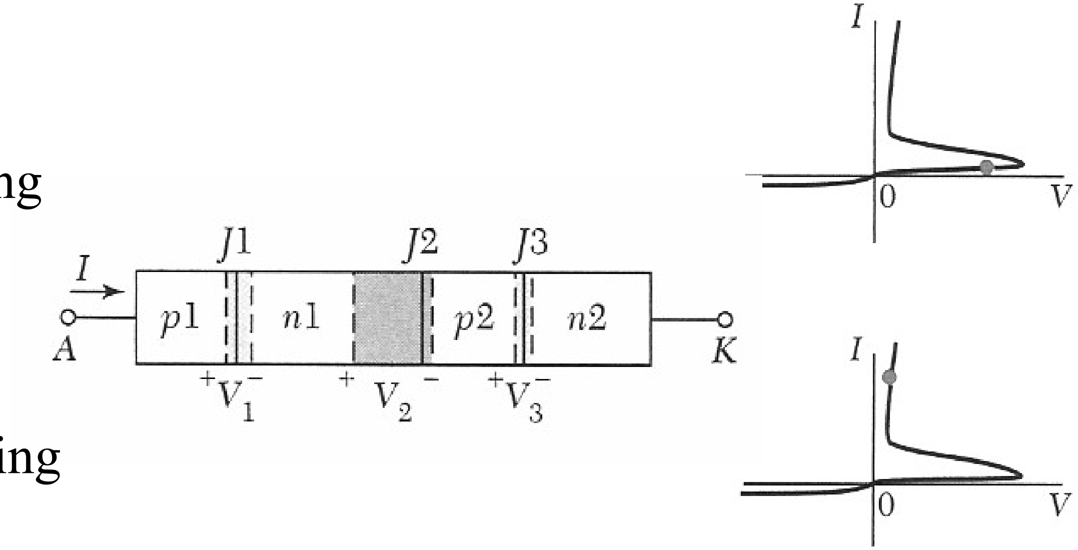
lightly doped p substrate

Used in front-end high-frequency receivers (mobile telephones).

Thyristors

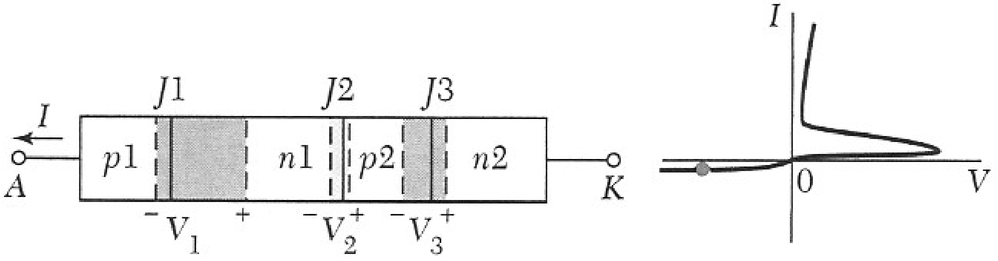


Forward blocking

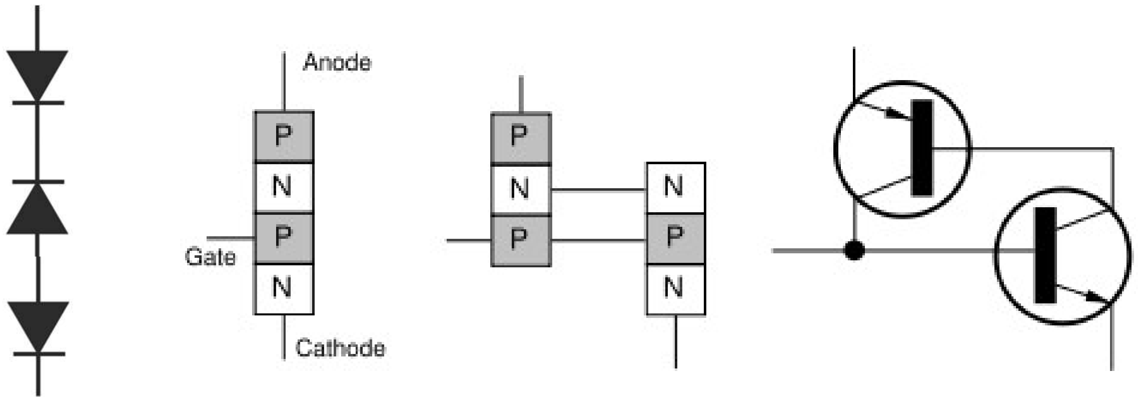


Forward conducting

Reverse blocking

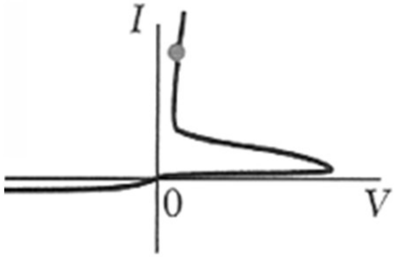


Thyristors

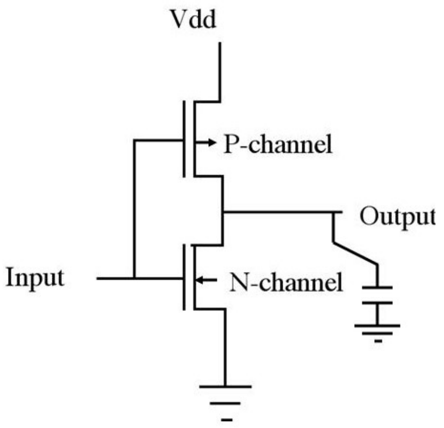


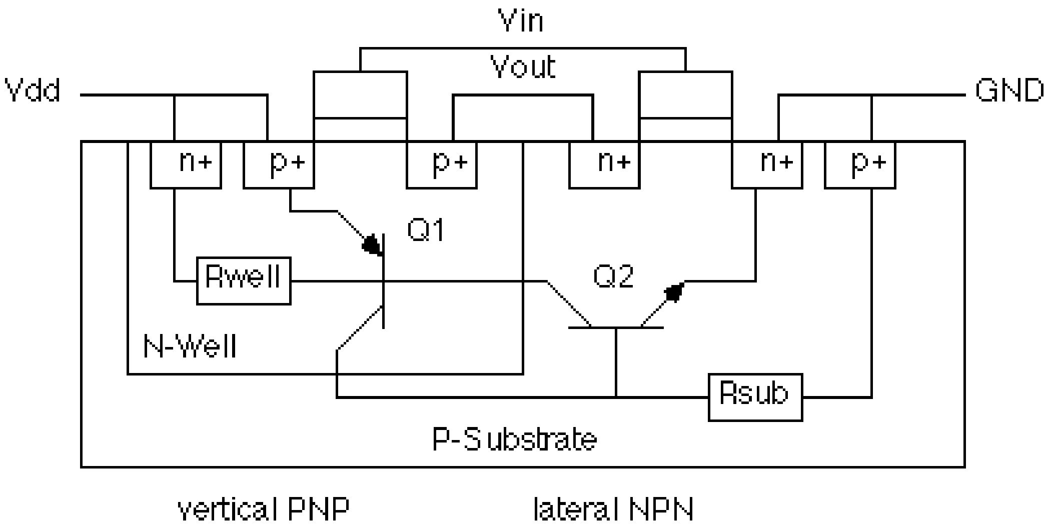
$\beta_1 * \beta_2 > 1$

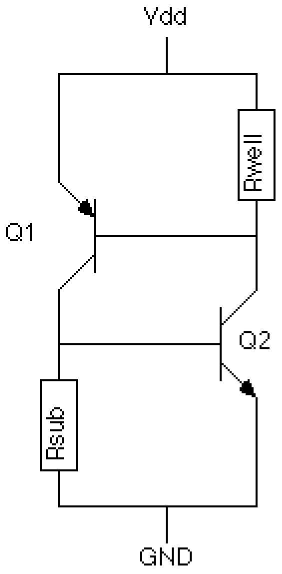
Used for switching high currents or voltages



Latch-up



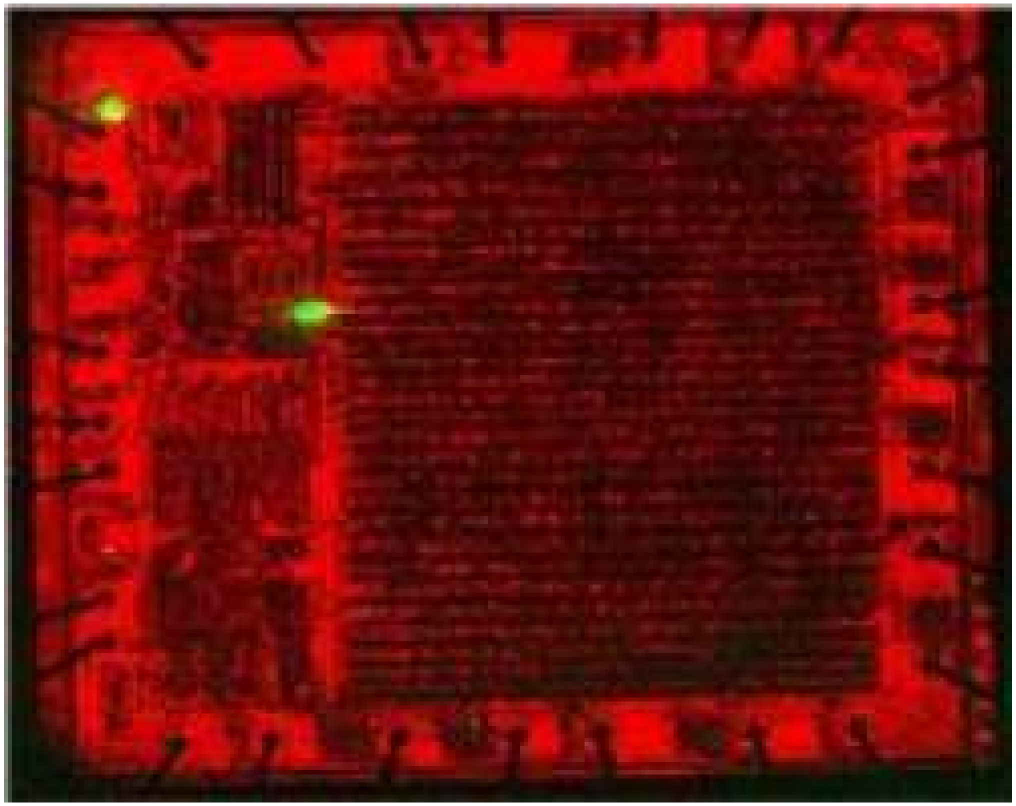




Both BJT's conduct, creating a low resistance path between V_{dd} and GND. The product of the gains of the two transistors in the feedback loop, is greater than one. The result of latchup is at the minimum a circuit malfunction, and in the worst case, the destruction of the device.

http://www.ece.drexel.edu/courses/ECE-E431/latch-up/latch-up.html

Emission Microscope



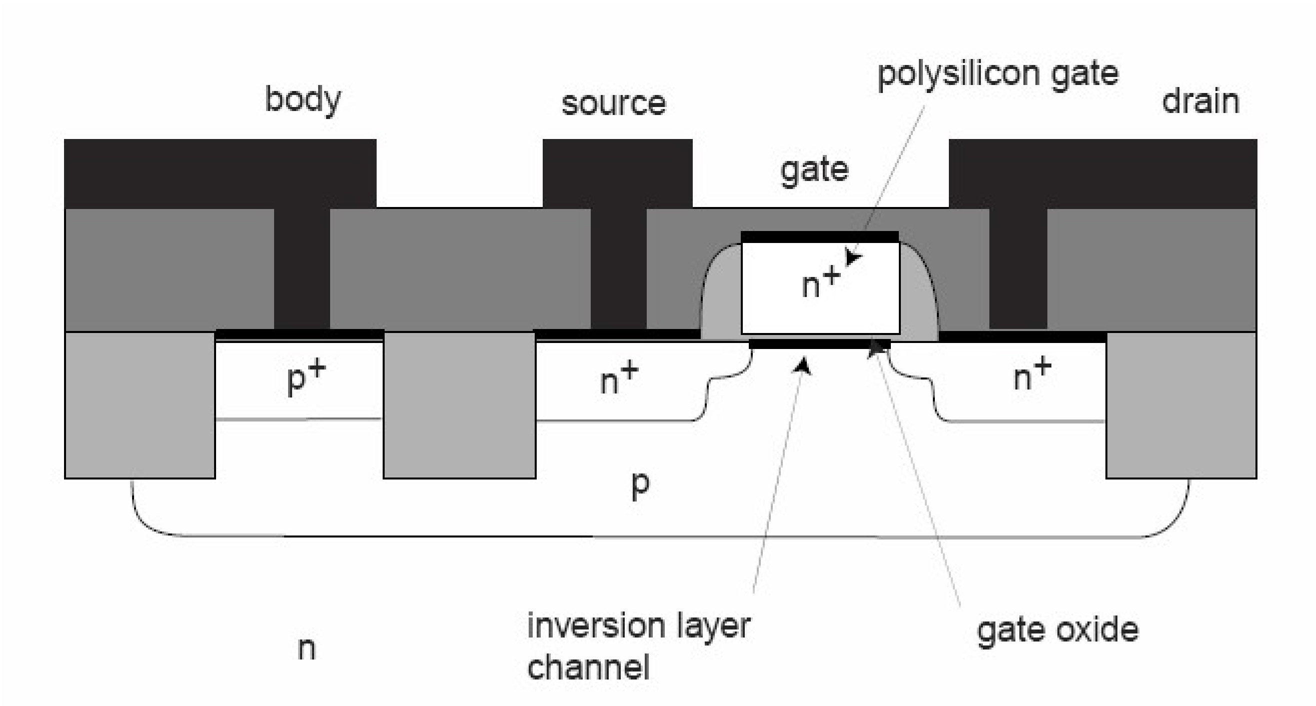
Forward biased diodes emit light. (BJT)
Defects often emit light.

http://www.muanalysis.com/techniques/emission-microscopy-emmi

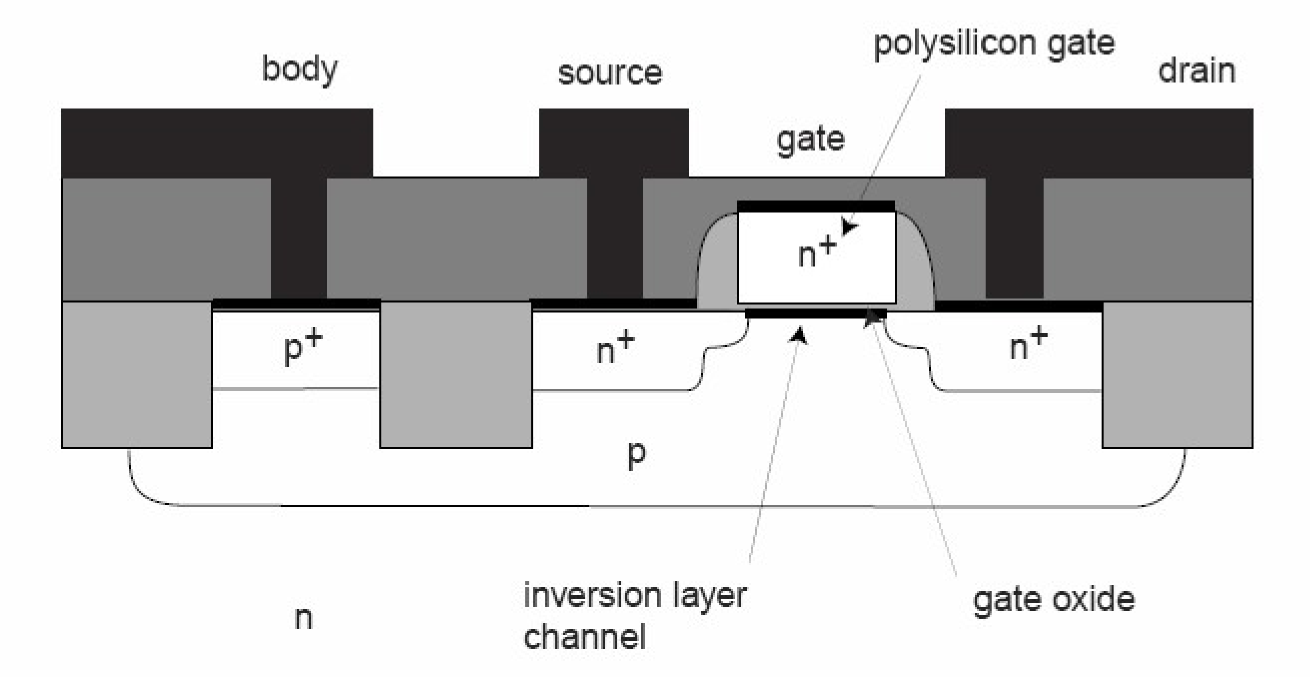
When does it emit light?

Thyristor
Bipolar junction transistors
MOSFET
JFET
Si diode

Can you operate like a BJT?



Subthreshold current

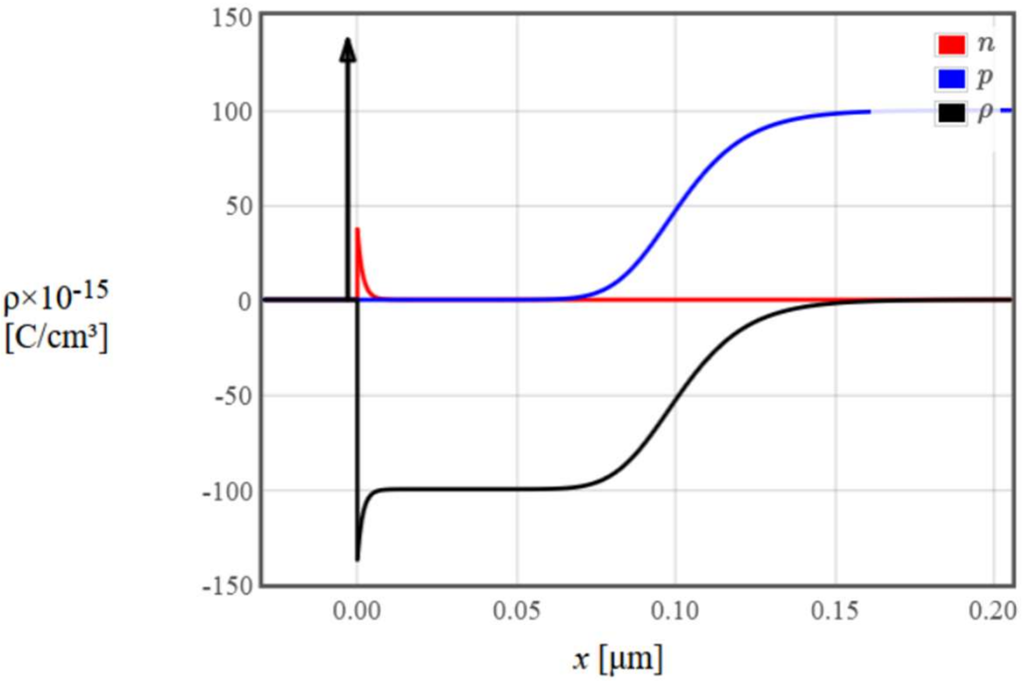


If the p-concentration in the channel is low, electrons emitted into the channel by the forward biased junction diffuse across the channel without recombining.

Subthreshold current – depletion approximation

$$x_p = -\frac{\epsilon_s}{\epsilon_{\text{ox}}} t_{\text{ox}} + \sqrt{\left(\frac{\epsilon_s}{\epsilon_{\text{ox}}} t_{\text{ox}}\right)^2 + \frac{2\epsilon_s}{eN_A}(V_g - V_{fb})}$$

$$n(x) = \begin{cases} \frac{n_i^2}{N_A} \exp\left(\frac{e^2 N_A (x_p - x)^2}{2\epsilon_s k_B T}\right) & \text{for } 0 < x < x_p, \\ \frac{n_i^2}{N_A} & \text{for } x > x_p, \end{cases}$$

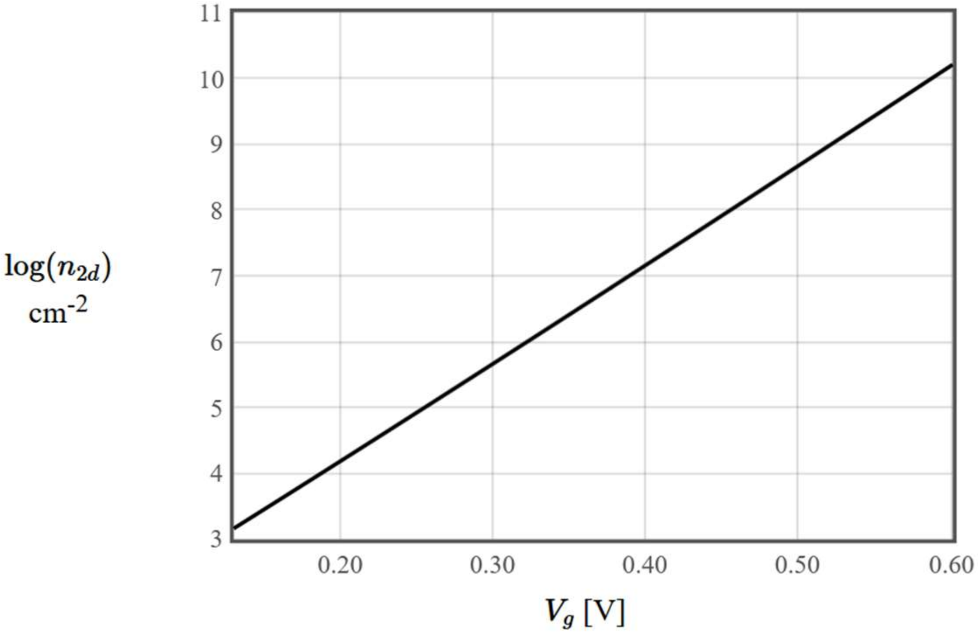


Subthreshold current – depletion approximation

$$n(x) = \frac{n_i^2}{N_A} \exp\left(\frac{e^2 N_A (x_p - x)^2}{2\epsilon_s k_B T} \right)$$

$$n(x) \approx \frac{n_i^2}{N_A} \exp\left(\frac{e^2 N_A (x_p^2 - 2x_p x)}{2\epsilon_s k_B T} \right)$$

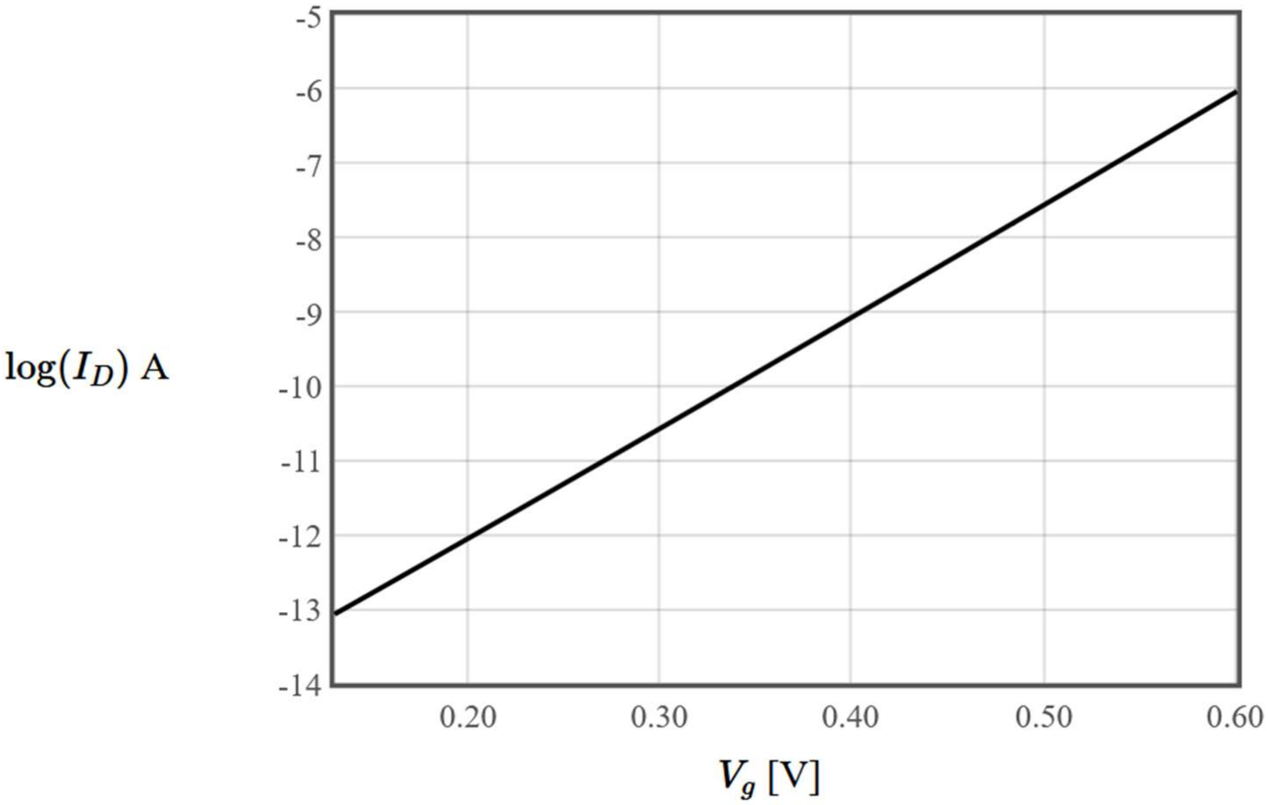
$$n_{2d} = \frac{n_i^2}{N_A} \exp\left(\frac{e^2 N_A x_p^2}{2\epsilon_s k_B T} \right) \frac{\epsilon_s k_B T}{e^2 N_A x_p}$$



Subthreshold current – depletion approximation

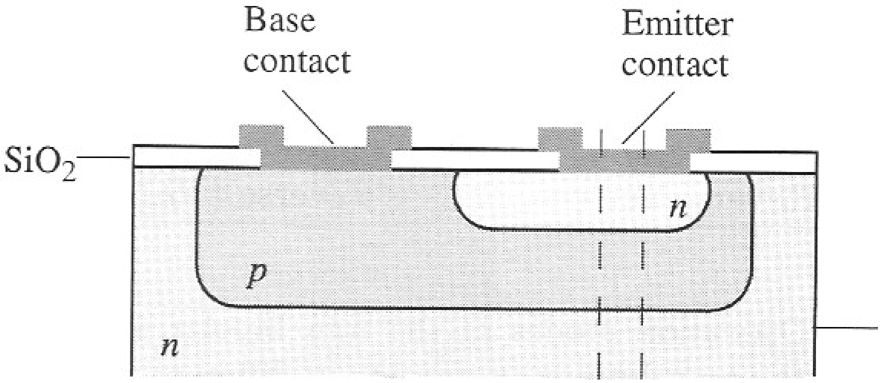
$$\nabla n \approx -\frac{n_{2d}}{L}$$

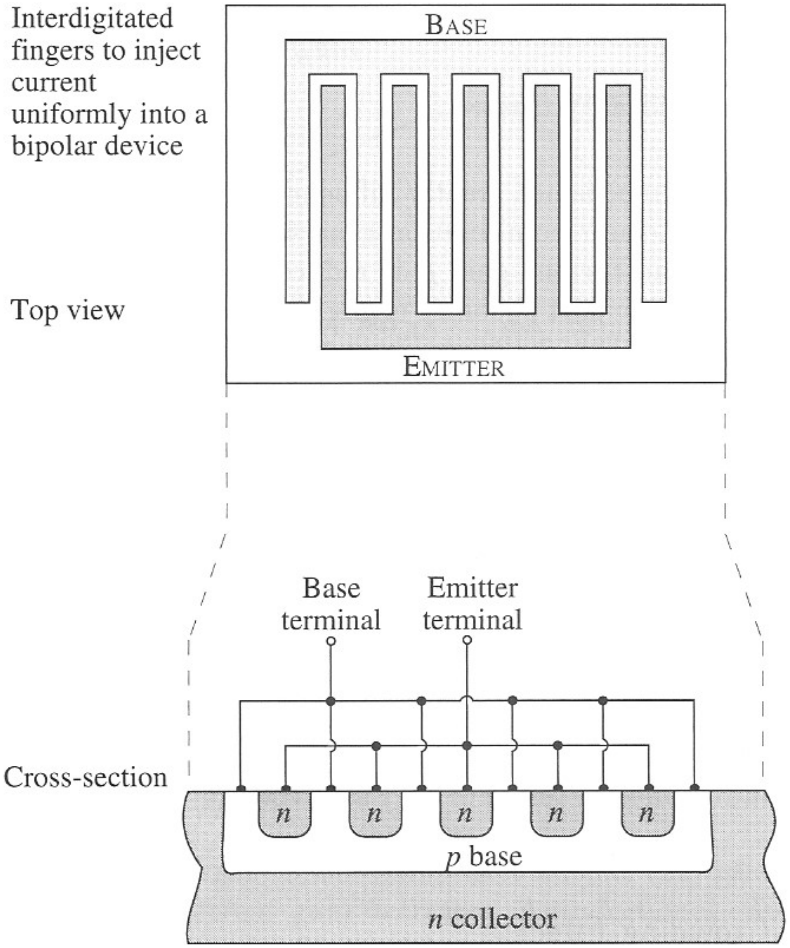
$$I_D \approx \frac{k_B T \mu W n_{2d}}{L} = \frac{n_i^2 \mu \epsilon_s k_B^2 T^2 W}{e^2 N_A^2 x_p L} \exp\left(\frac{e^2 N_A x_p^2}{2\epsilon_s k_B T}\right)$$

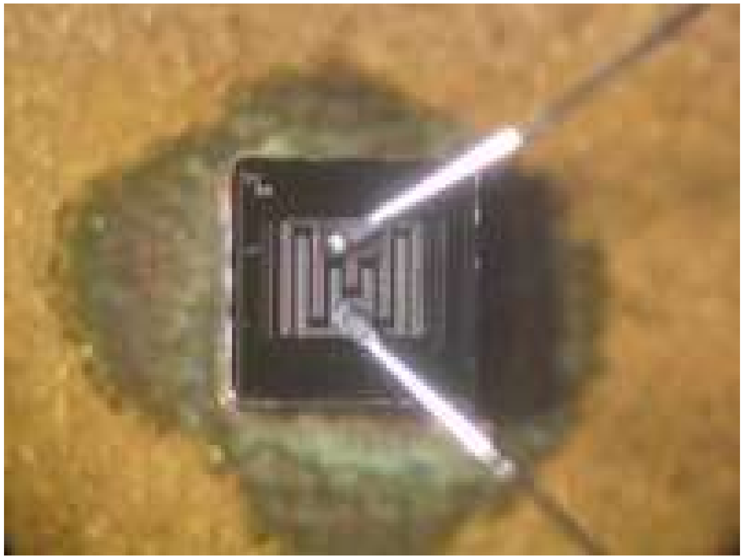


Subthreshold slope: 70-100 mV/decade

Interdigitated contacts in power transistors

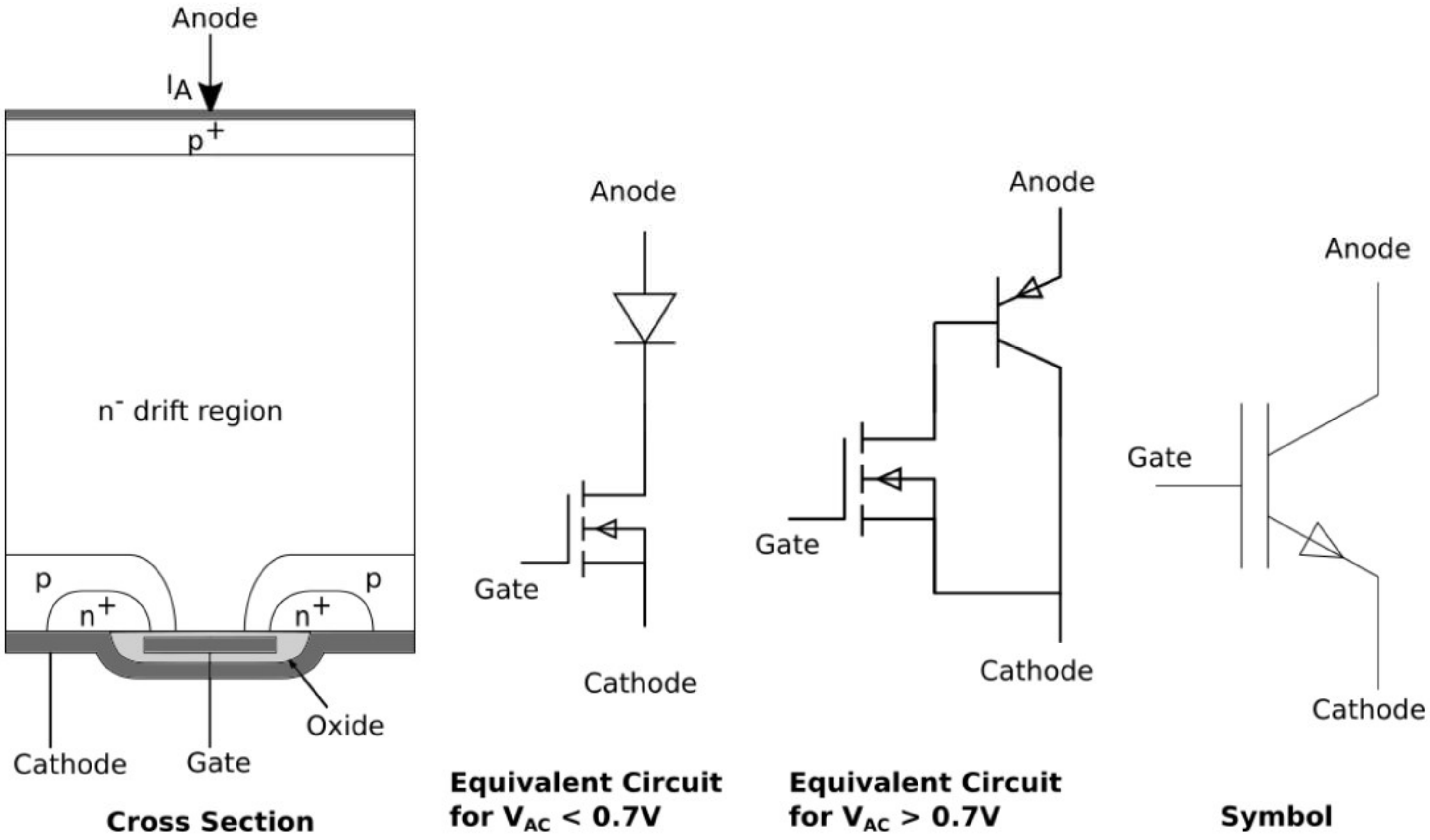



Interdigitated fingers to inject current uniformly into a bipolar device



IGBT - Insulated Gate Bipolar Transistor

An IGBT is a combination of an insulated gate FET and a bipolar transistor. It is primarily used for switching high power loads



Cross Section

Equivalent Circuit for V_{AC} < 0.7V

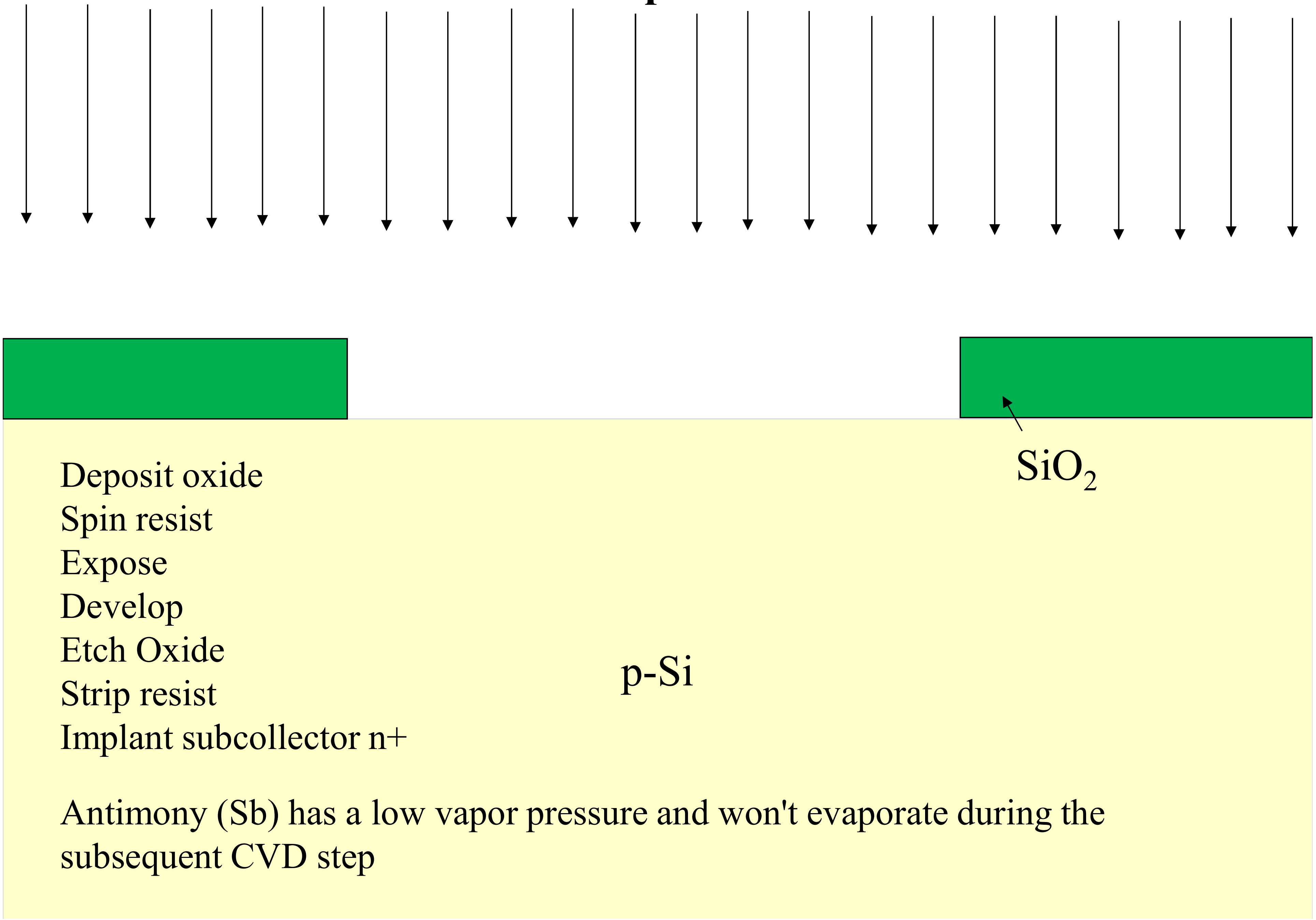
Equivalent Circuit for V_{AC} > 0.7V

Symbol

Used to switch large currents (in electric cars or trains).
Like a thyristor for high voltages.

http://lampx.tugraz.at/~hadley/psd/L13/igbt.html

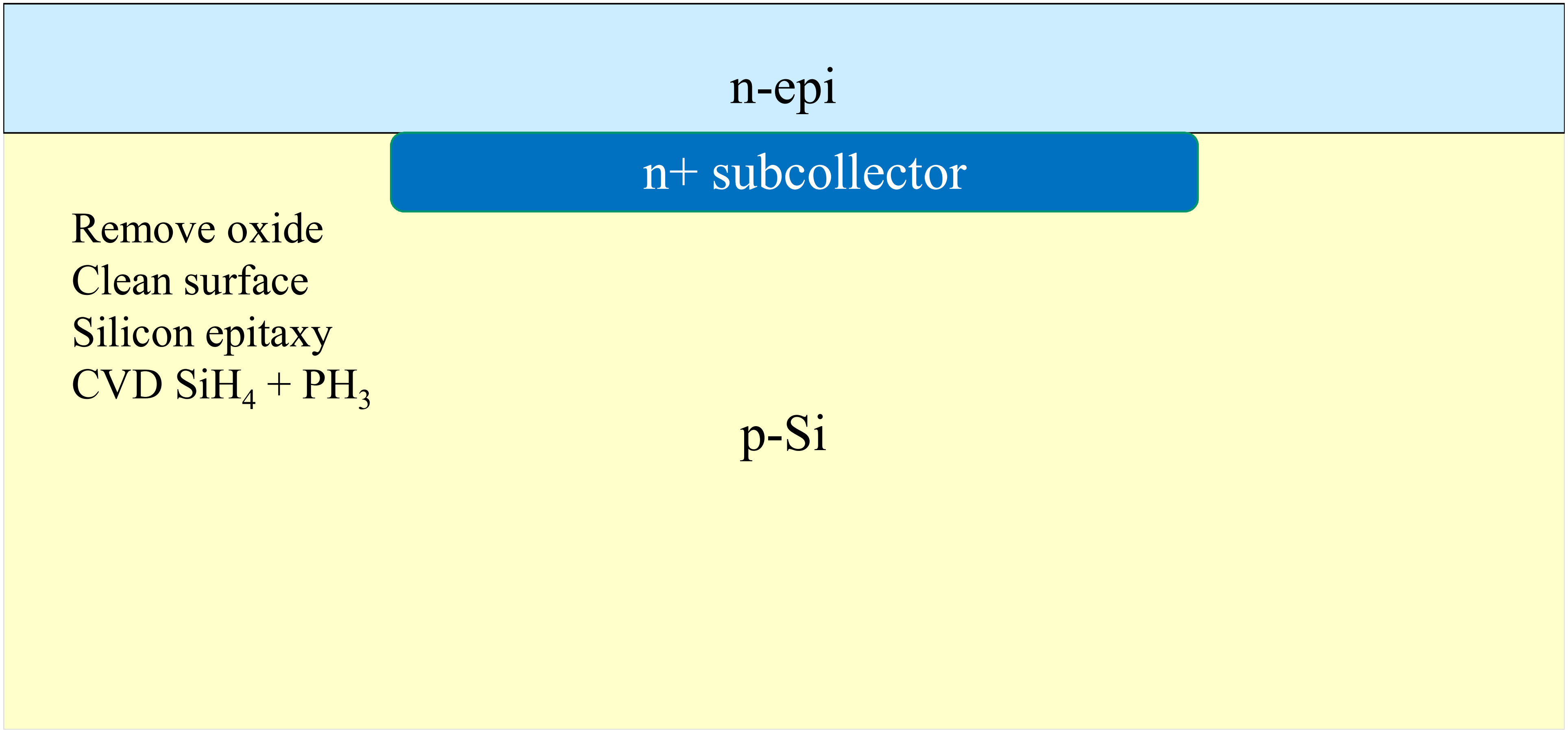
Implant



Deposit oxide
Spin resist
Expose
Develop
Etch Oxide
Strip resist
Implant subcollector n+

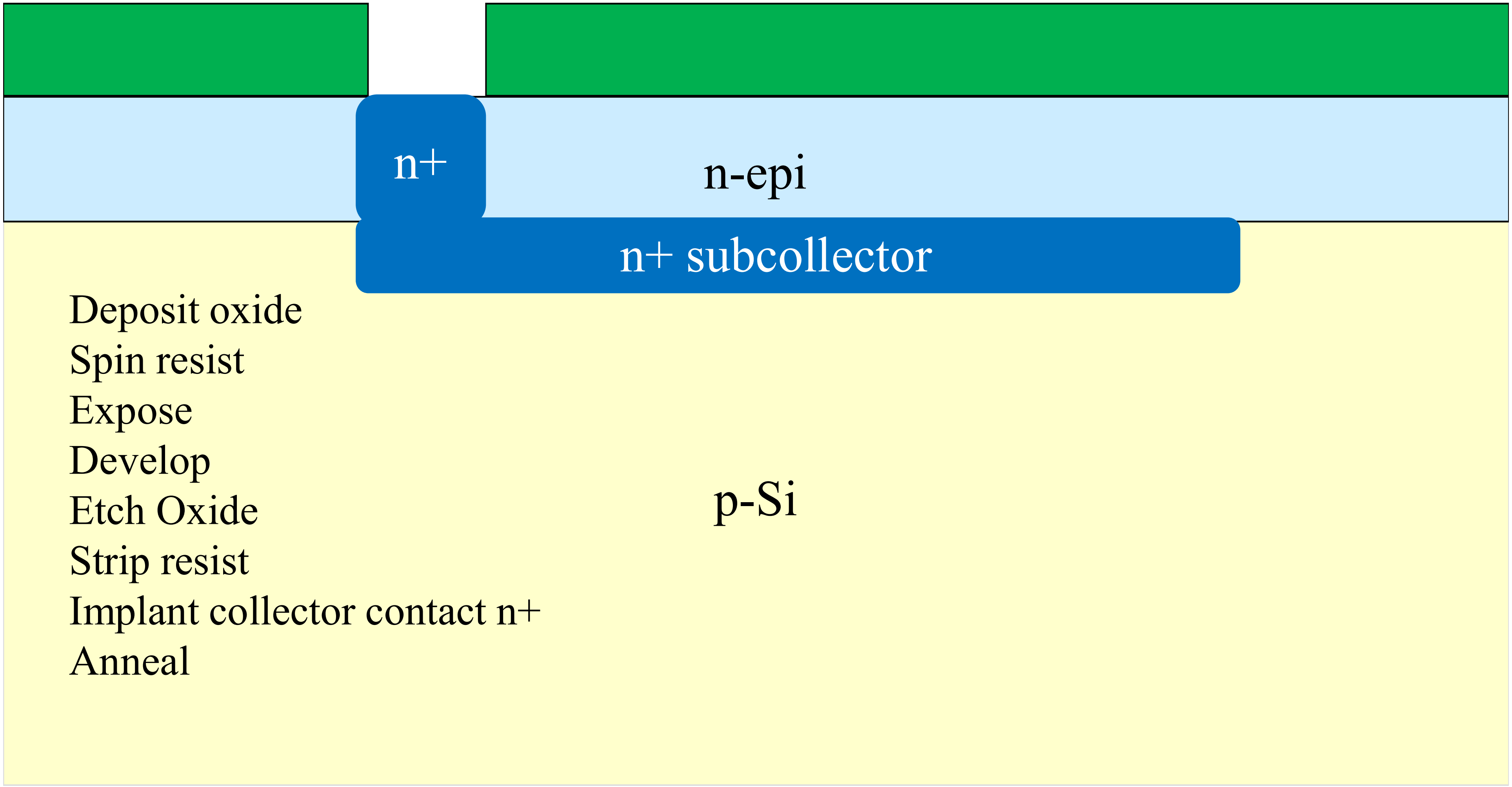
Antimony (Sb) has a low vapor pressure and won't evaporate during the subsequent CVD step

Epi-growth



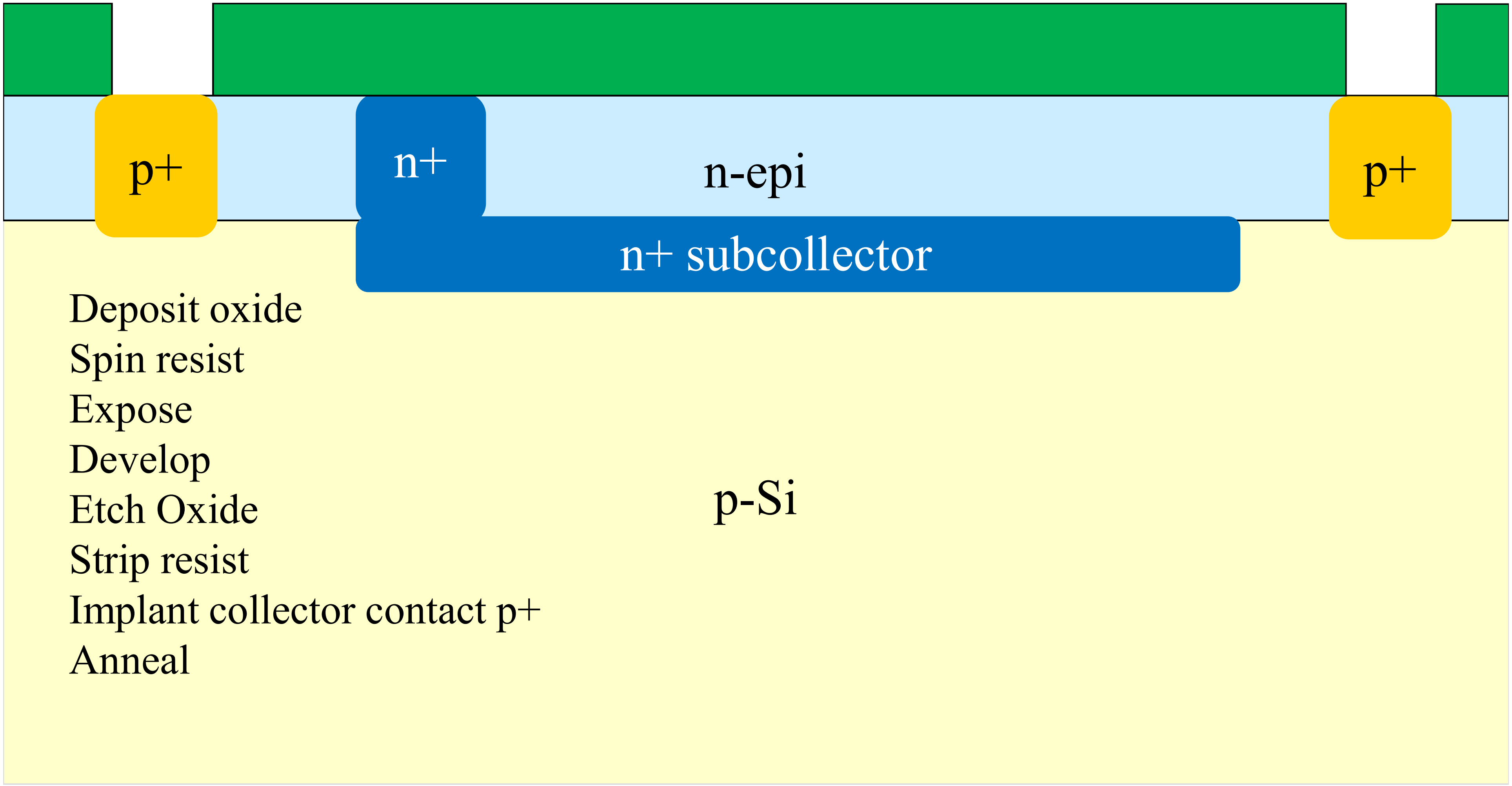
Remove oxide
Clean surface
Silicon epitaxy
CVD $SiH_4 + PH_3$

Collector Contact



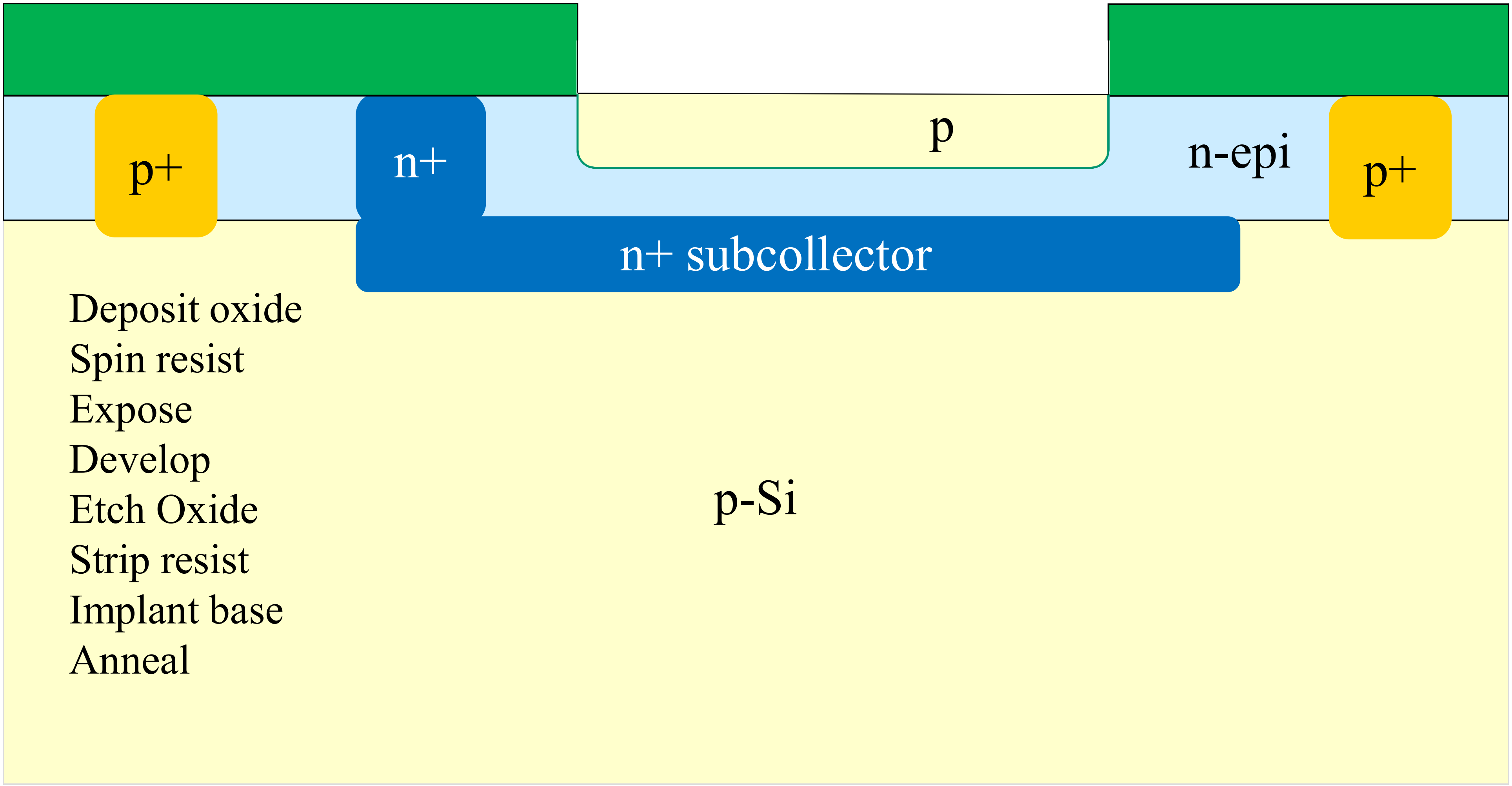
Deposit oxide
Spin resist
Expose
Develop
Etch Oxide
Strip resist
Implant collector contact n+
Anneal

Guard ring

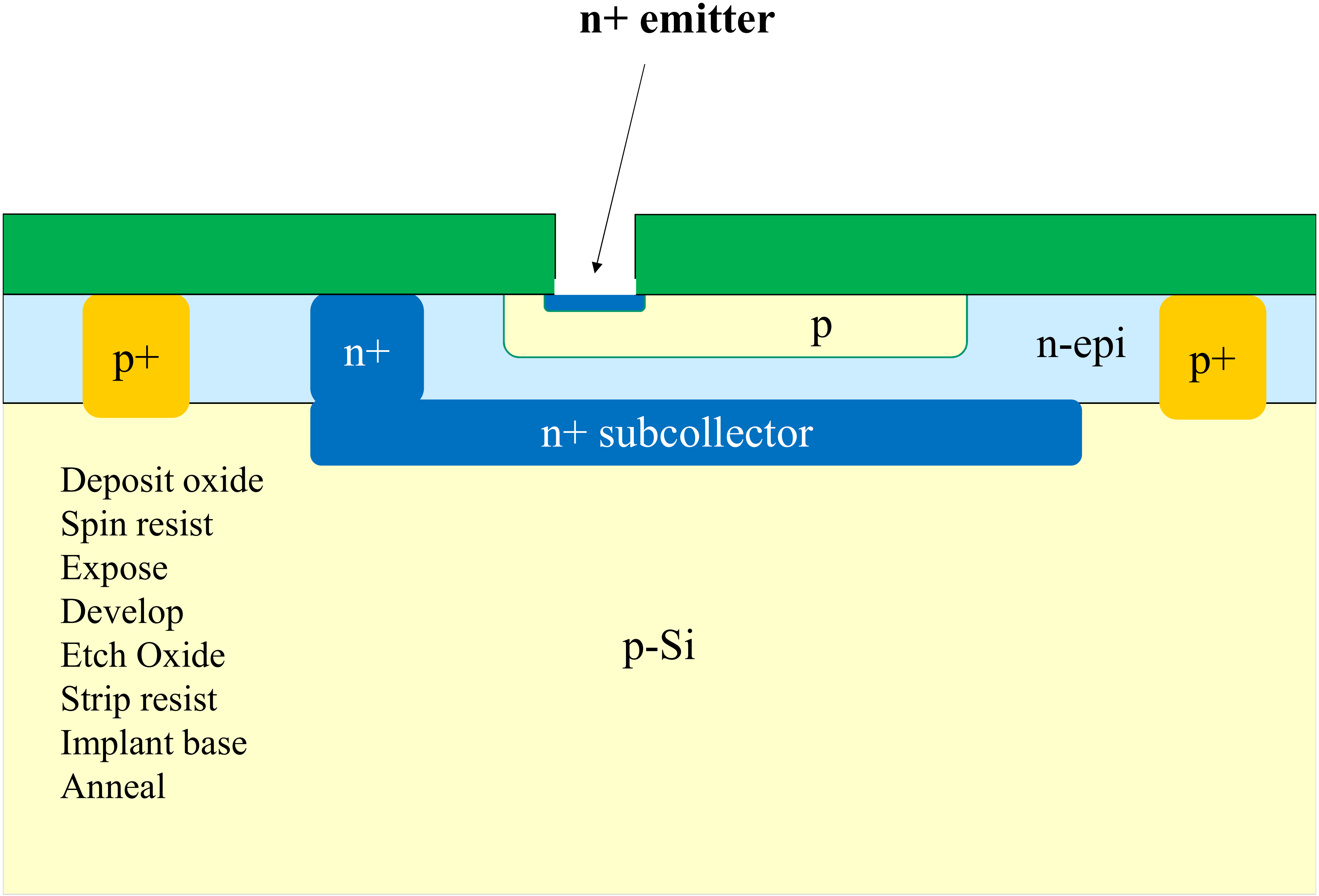


Deposit oxide
Spin resist
Expose
Develop
Etch Oxide
Strip resist
Implant collector contact p+
Anneal

p-well



Deposit oxide
Spin resist
Expose
Develop
Etch Oxide
Strip resist
Implant base
Anneal



Deposit oxide
Spin resist
Expose
Develop
Etch Oxide
Strip resist
Implant base
Anneal

BiCMOS

Only one additional step to CMOS is needed for BiCMOS

Bipolar junction transistors:
high speed
high gain
low output impedance
good for analog amplifiers

CMOS
high impedance
low power logic

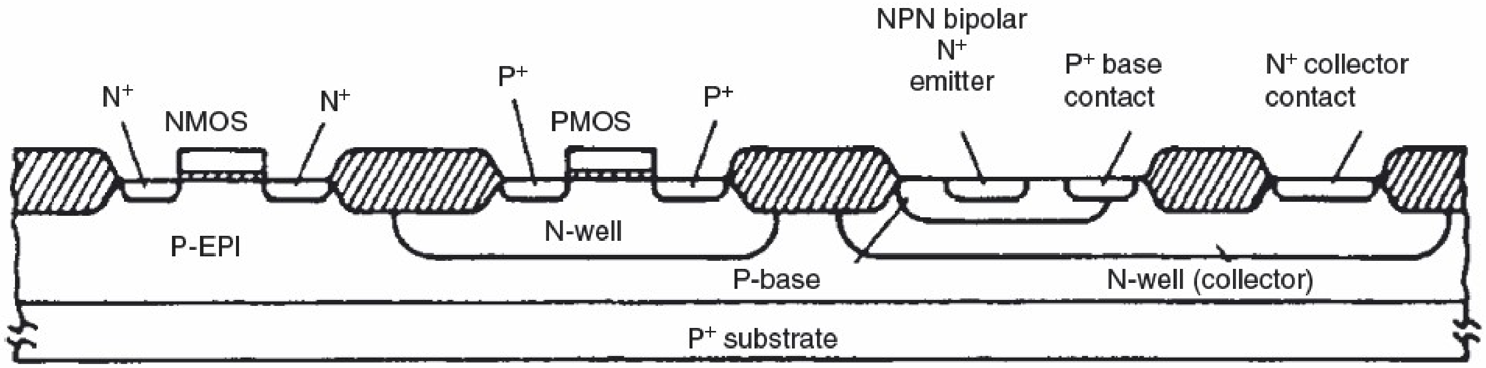


Figure 27.6 Simple BiCMOS technology: triple diffused-type bipolar transistor added to a CMOS process with minimal extra steps: only p-base diffusion mask is added to CMOS process flow. Reproduced from Alvarez (1989) by permission of Kluwer

Fransila

See: http://www.iue.tuwien.ac.at/phd/puchner/node48_app.html

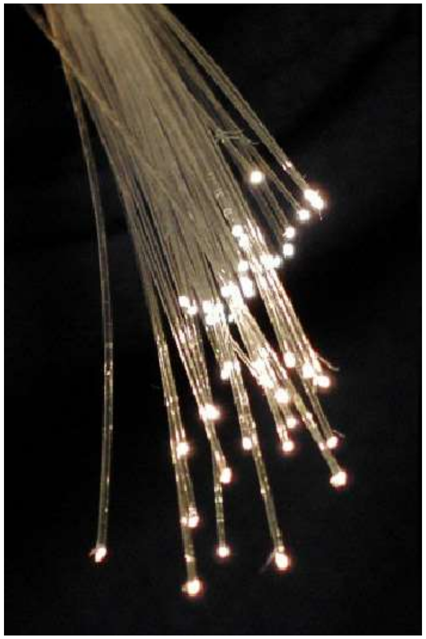
Optoelectronics

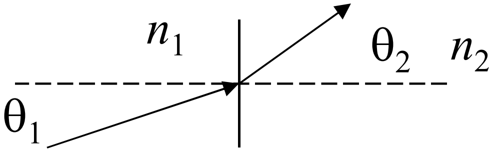
Optoelectronics

light emitting diode
laser diode
solar cell
photo detectors

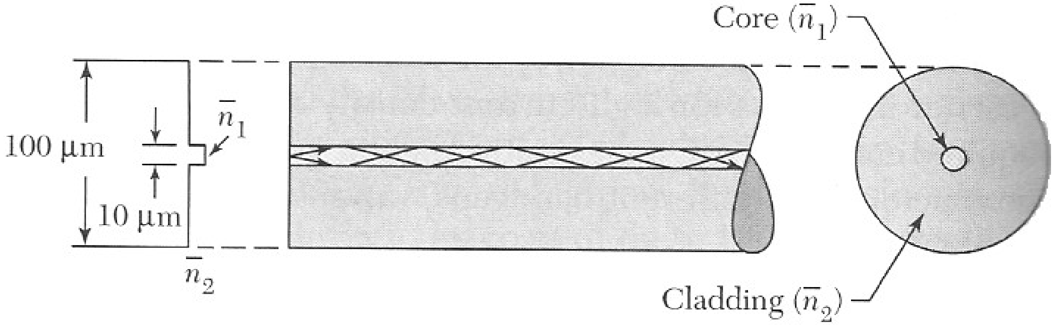
communications, memory (DVD), displays, printing, bar-code readers, solar energy, lighting, laser surgery, measurement, guidance, spectroscopy, LiFi

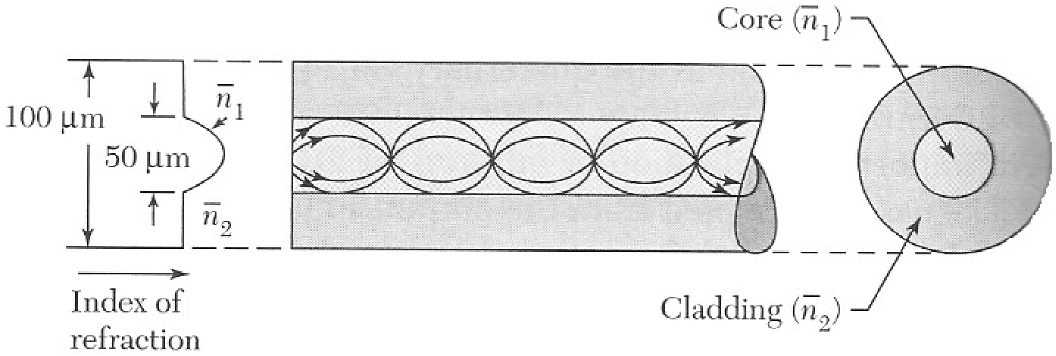
Confinement of light by total internal reflection



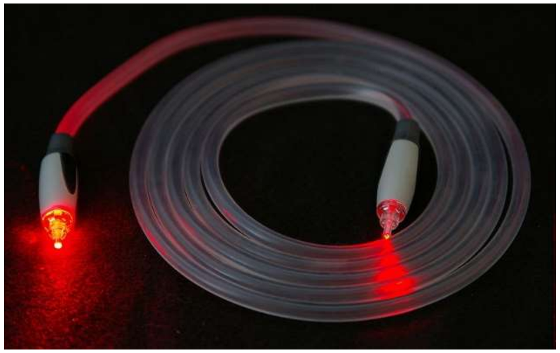


$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



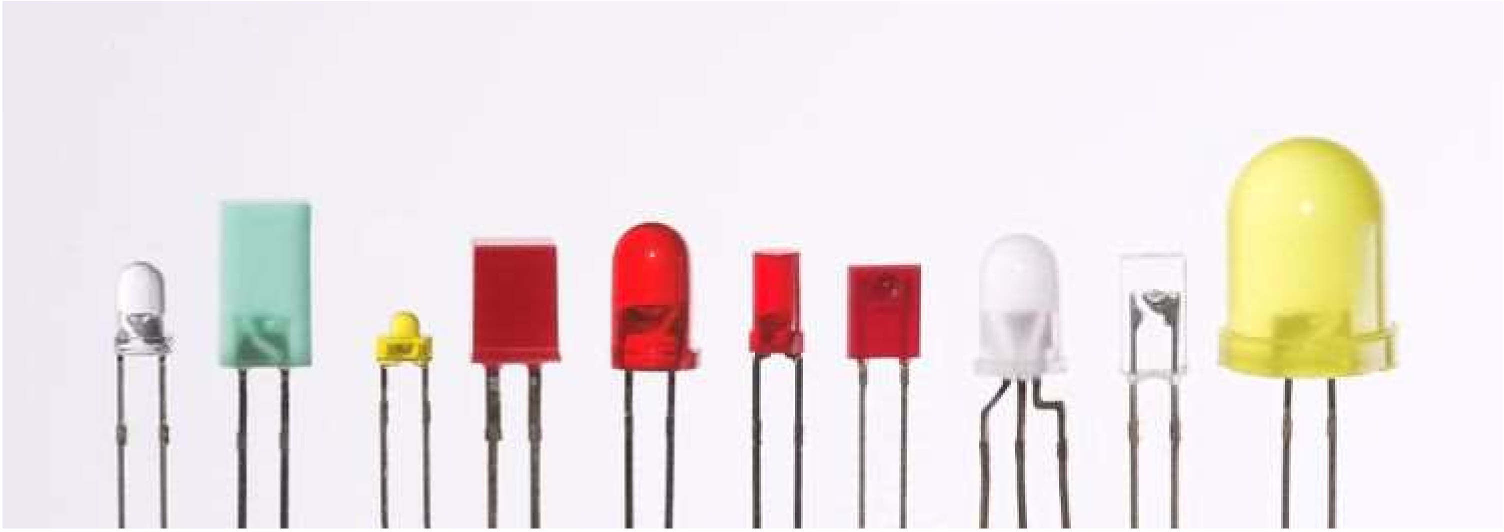


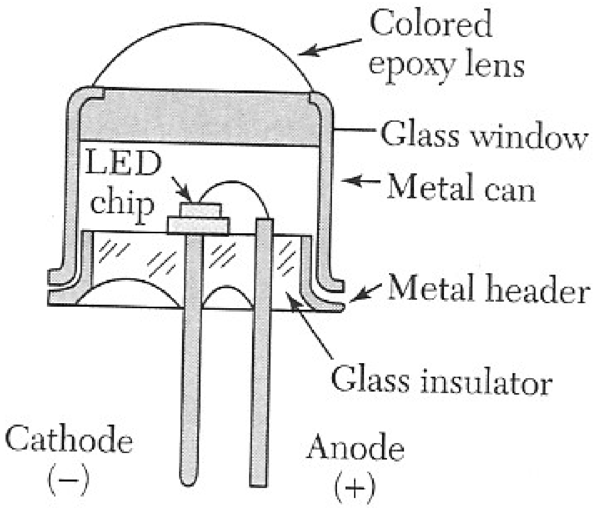
less pulse spreading for parabolically graded fiber

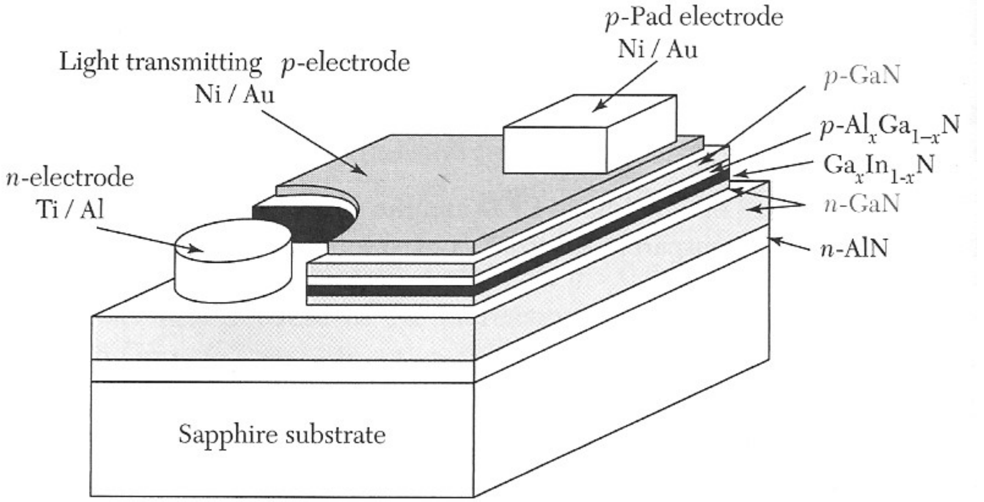


0.6 dB/km at 1.3 µm and 0.2 dB/km at 1.55 µm

Light emitting diodes



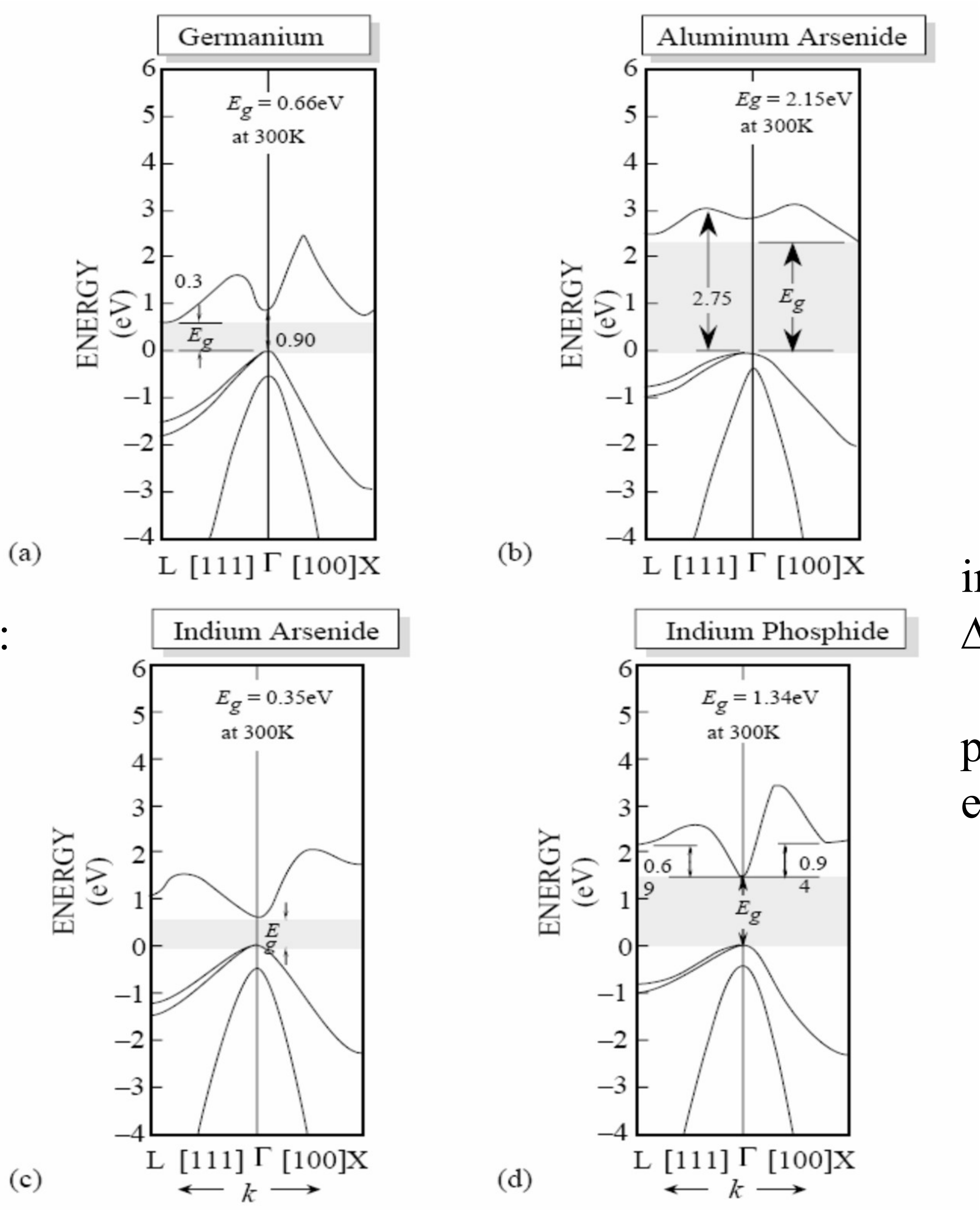




Solid state lighting is efficient.

direct bandgap:
$\Delta k = 0$

photons can be emitted



indirect bandgap:
$\Delta k \neq 0$

phonons are emitted

Light emitting diodes

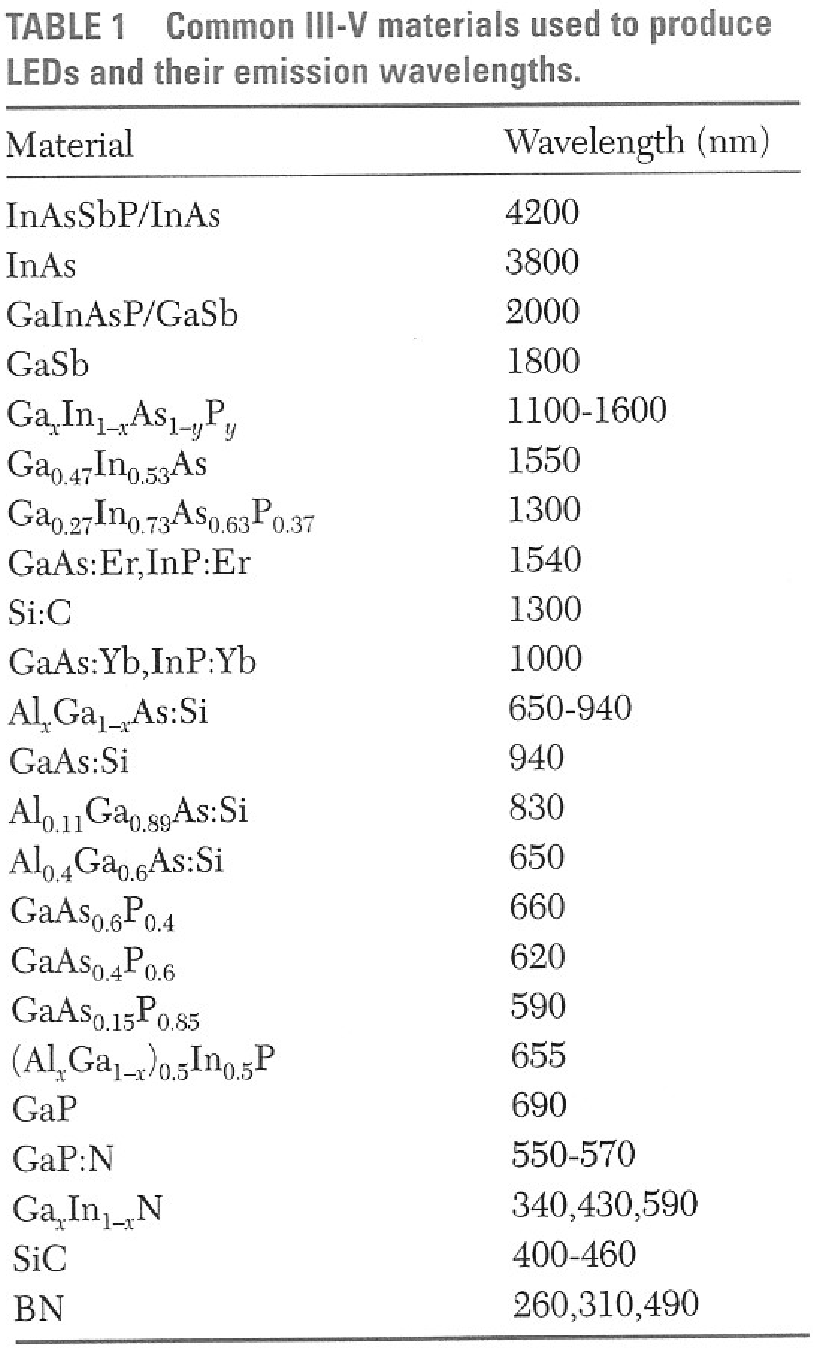
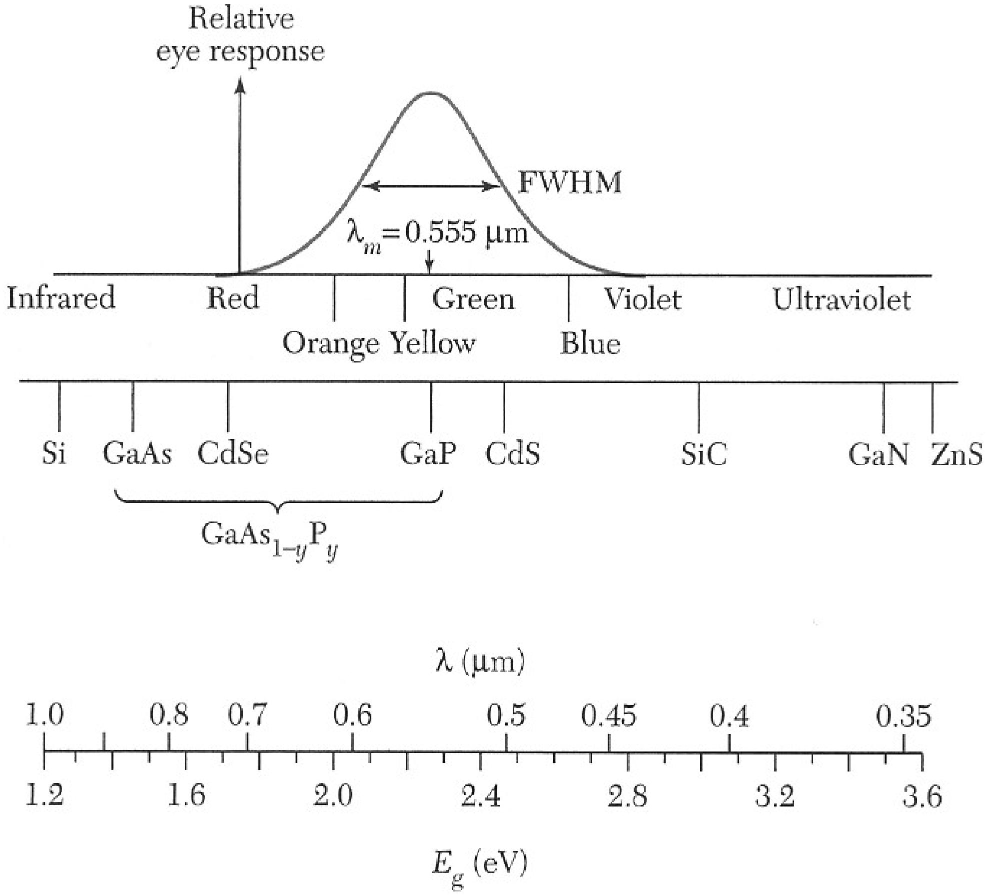
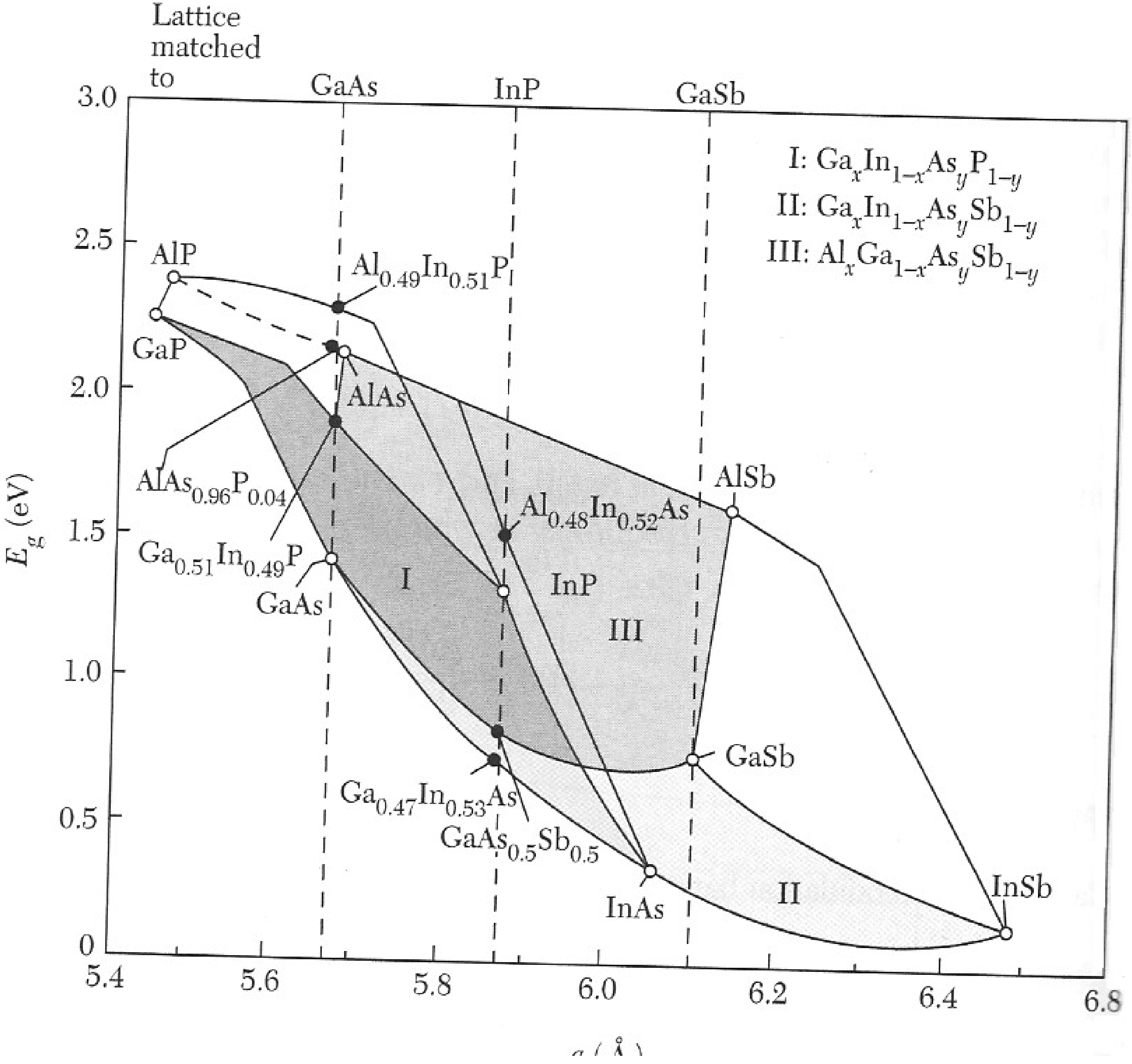


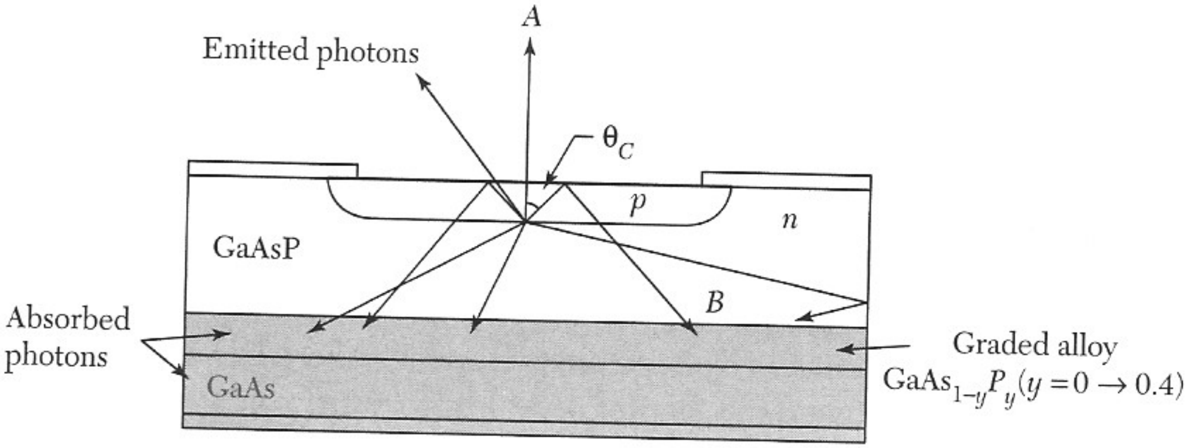
TABLE 1 Common III-V materials used to produce LEDs and their emission wavelengths.

Material	Wavelength (nm)
InAsSbP/InAs	4200
InAs	3800
GaInAsP/GaSb	2000
GaSb	1800
$Ga_xIn_{1-x}As_{1-y}P_y$	1100-1600
$Ga_{0.47}In_{0.53}As$	1550
$Ga_{0.27}In_{0.73}As_{0.63}P_{0.37}$	1300
GaAs:Er,InP:Er	1540
Si:C	1300
GaAs:Yb,InP:Yb	1000
$Al_xGa_{1-x}As$:Si	650-940
GaAs:Si	940
$Al_{0.11}Ga_{0.89}As$:Si	830
$Al_{0.4}Ga_{0.6}As$:Si	650
$GaAs_{0.6}P_{0.4}$	660
$GaAs_{0.4}P_{0.6}$	620
$GaAs_{0.15}P_{0.85}$	590
$(Al_xGa_{1-x})_{0.5}In_{0.5}P$	655
GaP	690
GaP:N	550-570
$Ga_xIn_{1-x}N$	340,430,590
SiC	400-460
BN	260,310,490

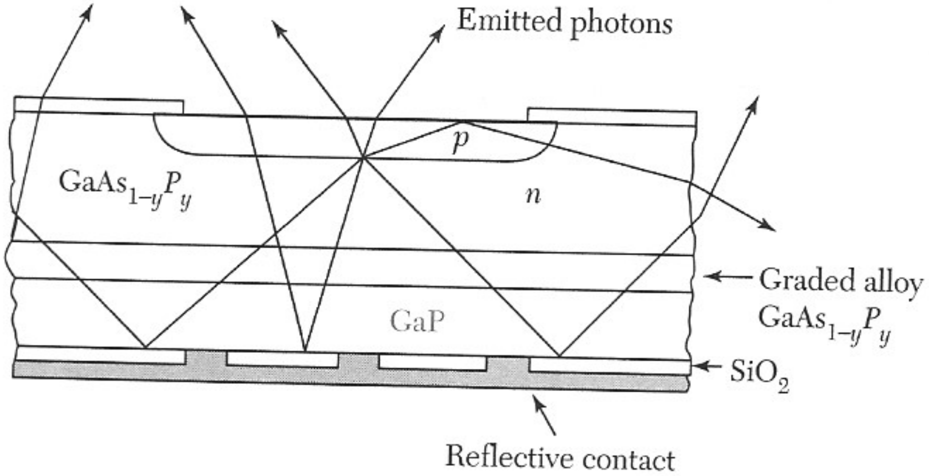



Lattice matched to
GaAs
InP
GaSb
I: $Ga_xIn_{1-x}As_yP_{1-y}$
II: $Ga_xIn_{1-x}As_ySb_{1-y}$
III: $Al_xGa_{1-x}As_ySb_{1-y}$
AlP
GaP
$Al_{0.49}In_{0.51}P$
AlAs
$AlAs_{0.96}P_{0.04}$
$Ga_{0.51}In_{0.49}P$
GaAs
I
$Al_{0.48}In_{0.52}As$
InP
III
AlSb
GaSb
$Ga_{0.47}In_{0.53}As$
$GaAs_{0.5}Sb_{0.5}$
InAs
II
InSb
E_g (eV)
3.0
2.5
2.0
1.5
1.0
0.5
0
5.4
5.6
5.8
6.0
6.2
6.4
6.8
a (Å)

Light emitting diodes



absorption
reflection
total internal reflection



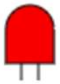
- Home
- Outline
- Introduction
- Electrons in crystals
- Intrinsic Semiconductors
- Extrinsic Semiconductors
- Transport
- pn junctions
- Contacts
- JFETs/MESFETs
- MOSFETs
- Bipolar transistors
- Opto-electronics
- Lectures
- Books
- Exam questions
- Html basics
- TUG students
- Student projects
- Print version

Light Emitting Diode

A Light Emitting Diode (LED) consists of a pn-diode in a semiconductor with a direct bandgap. When the diode is forward biased, the electrons and the holes are pushed towards the junction where they recombine. The photons that are emitted have the energy of the band gap, $E_g = \frac{hc}{\lambda}$. The slider below lets you select a wavelength. The corresponding bandgap to this wavelength is calculated and the approximate color is shown. For some bandgap energies, the composition of a direct bandgap semiconductor that will emit this wavelength is shown.

λ = 650 nm - +

E_g = 1.91 eV visible



$Al_{0.39}Ga_{0.61}As$ $GaAs_{0.39}P_{0.61}$

Below, simplified band diagrams can be displayed for some semiconductors. The electrons in the conduction band are primarily located at the minimum of the conduction band and the holes in the valence band are concentrated at the maximum of the valence band. The electrons are thermally excited up to about k_BT above the conduction band minimum and the holes are excited to about k_BT below the valence band maximum. When the electrons and holes recombine, this results in photon energies approximately in the range $E_g \pm k_BT$.

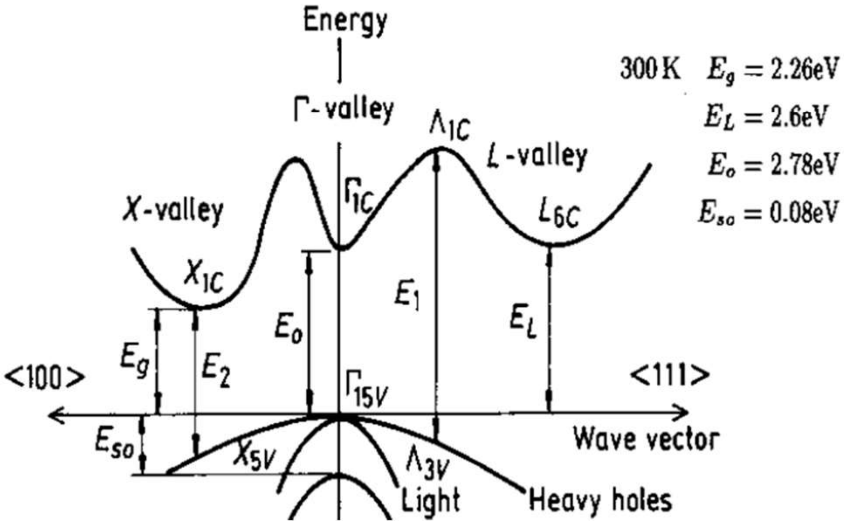


Photo detectors

Intrinsic semiconductor $\sigma = e(\mu_n n + \mu_p p)$ (used in copiers)

Unbiased pn junction - like a solar cell

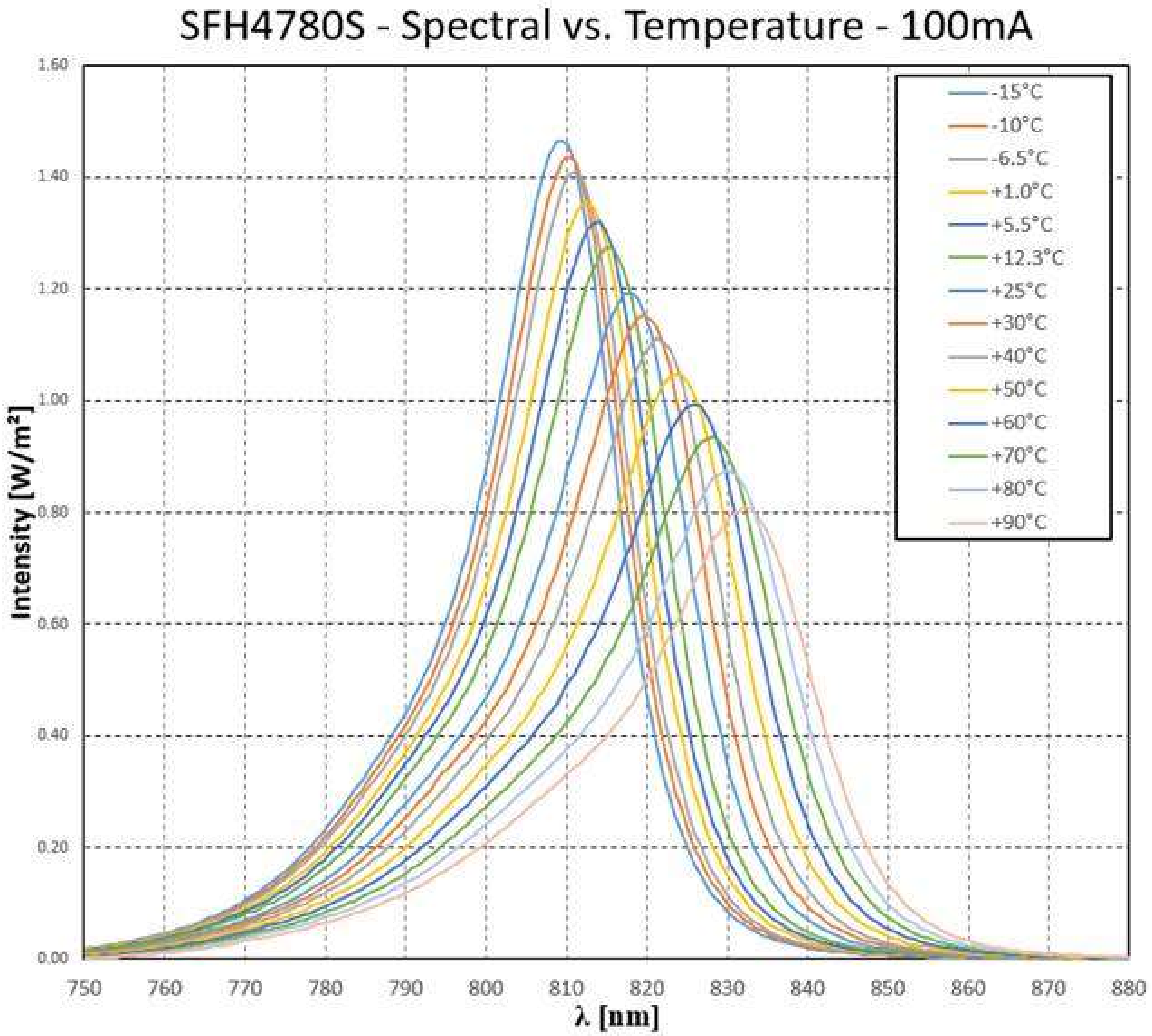
Reverse biased pn junction - smaller capacitance, higher speed, less noise

Phototransistor - light injects carriers into the base. This forward biases the emitter base junction. High responsivity.

Ambient light detectors.

Active Pixel sensors for automated parking and gesture control (uses time-of-flight to image in 3-D).

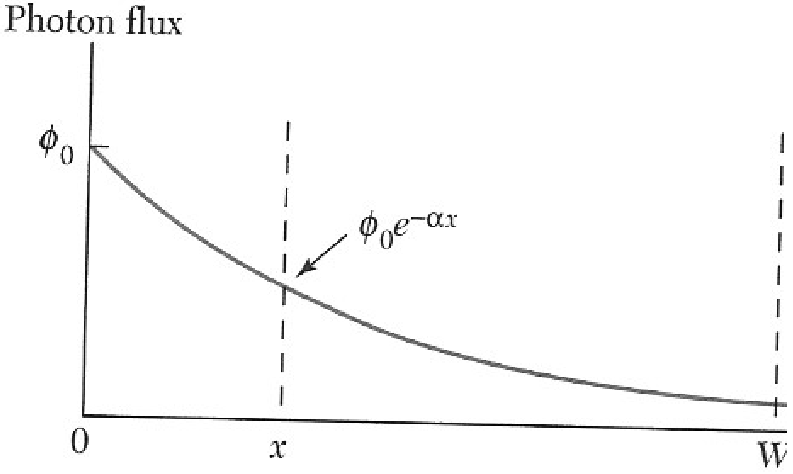
IR LED



Measurement by Jan Enenkel

Absorption

Photon flux: $\Phi(x) = \Phi_0 e^{-\alpha x}$

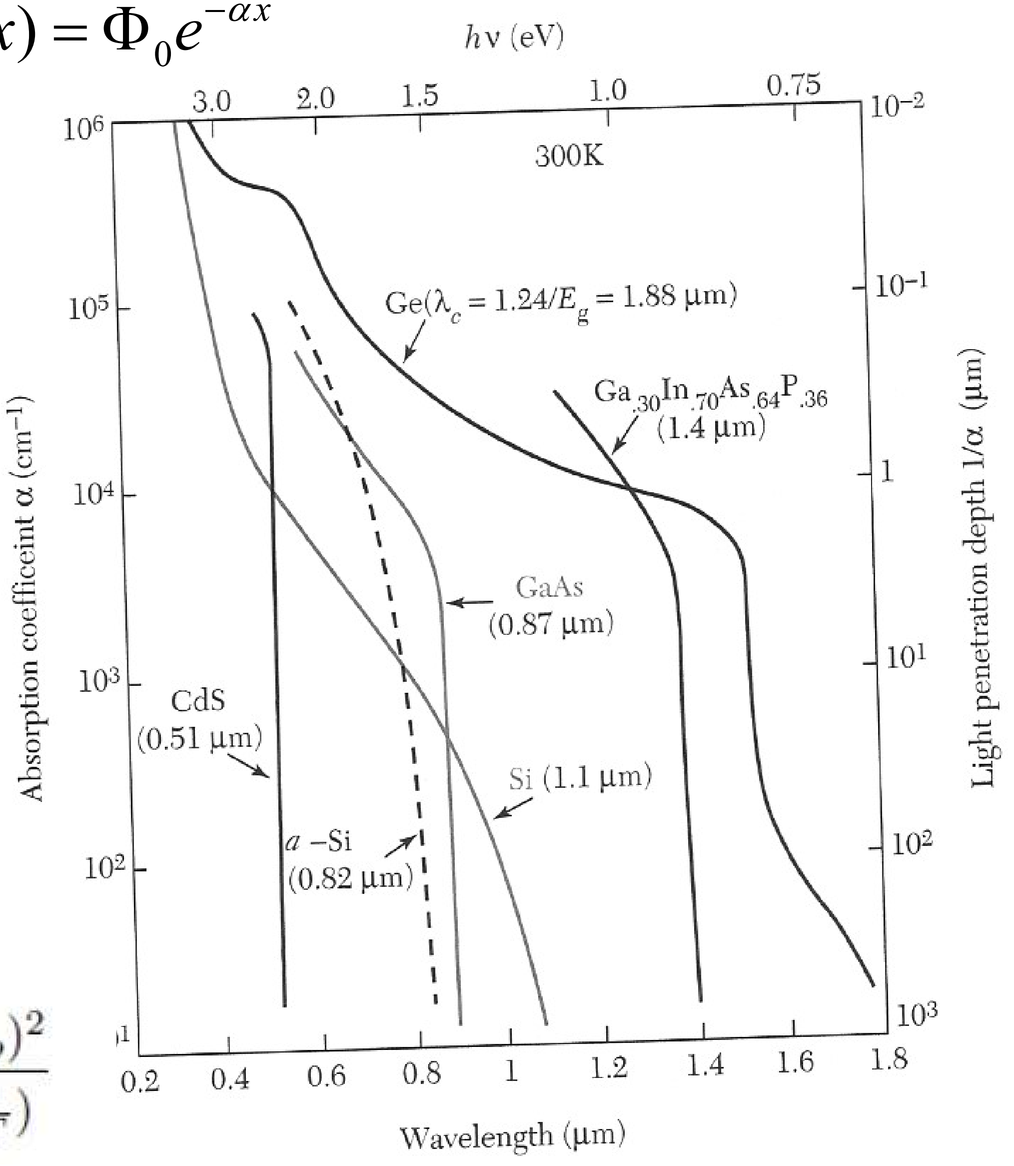


Sharp absorption edge for direct bandgap materials

$$\alpha \approx 3.5\times 10^{6}\left(\frac{m_r^*}{m_0}\right)^{3/2}\frac{\sqrt{\hbar\omega - E_g}}{\hbar\omega} \quad \text{cm}^{-1}$$

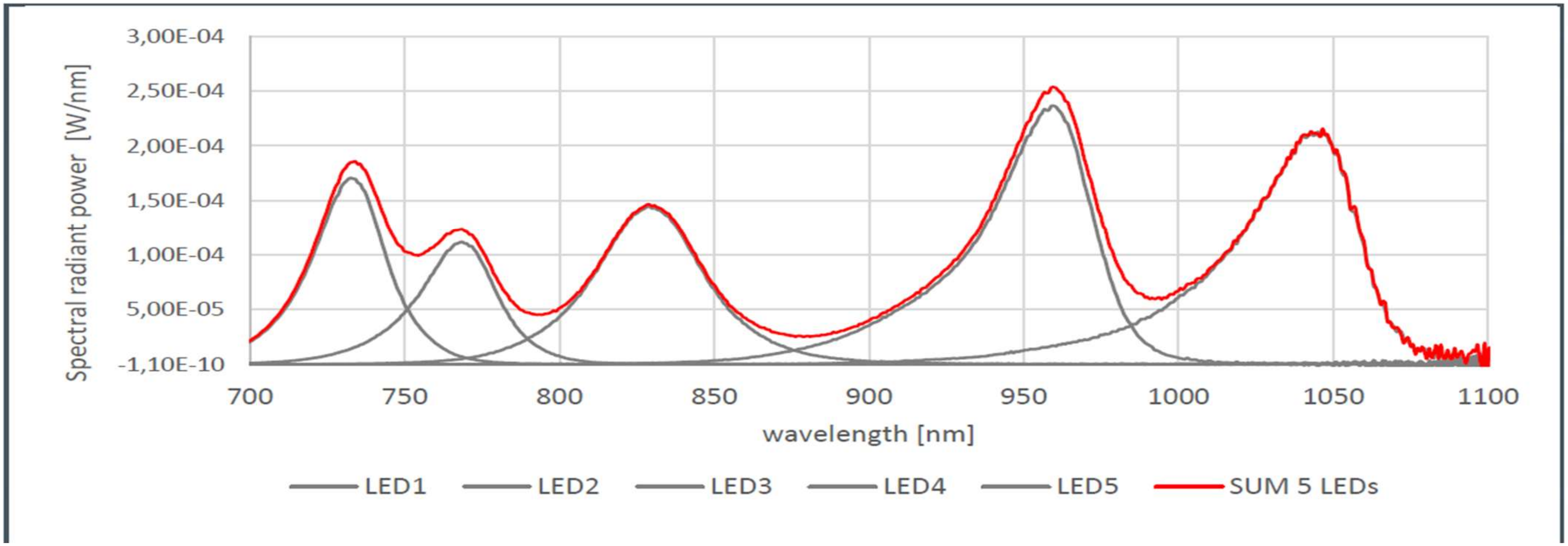
direct bandgap   indirect bandgap

$$\alpha \propto \frac{(h\nu - E_g + E_p)^2}{exp(\frac{E_p}{k_B T}) - 1} + \frac{(h\nu - E_g - E_p)^2}{1 - exp(-\frac{E_p}{k_B T})}$$



AS7420 64-channel hyperspectral near infrared sensor

Typical LED Spectral Emission at 50mA LED current



AS7420 64-channel hyperspectral near infrared sensor