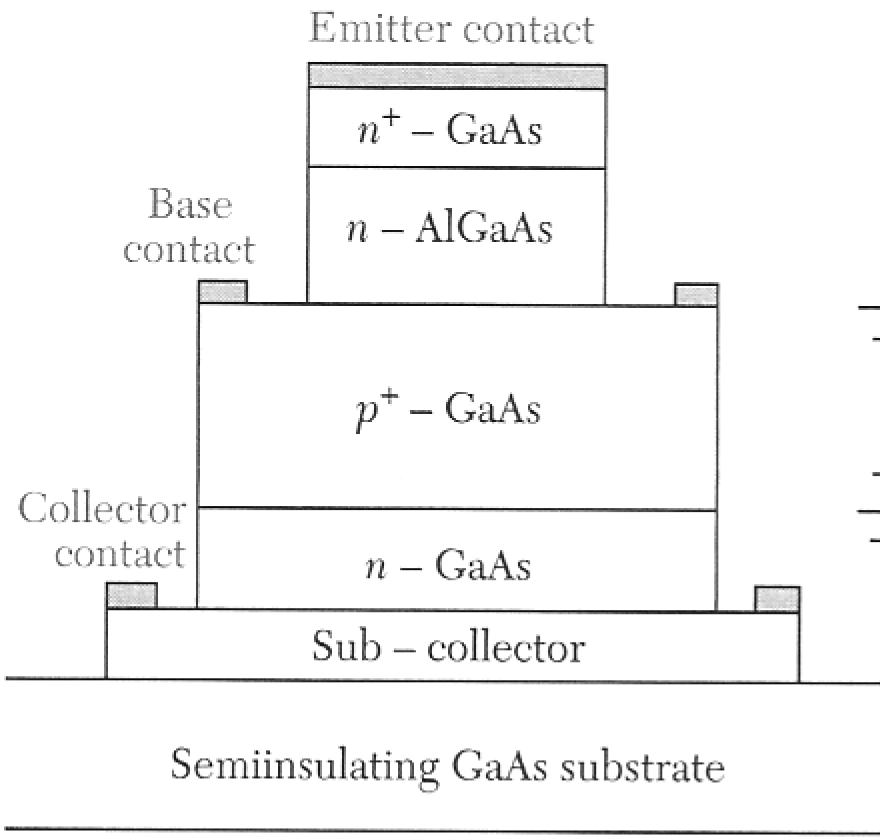
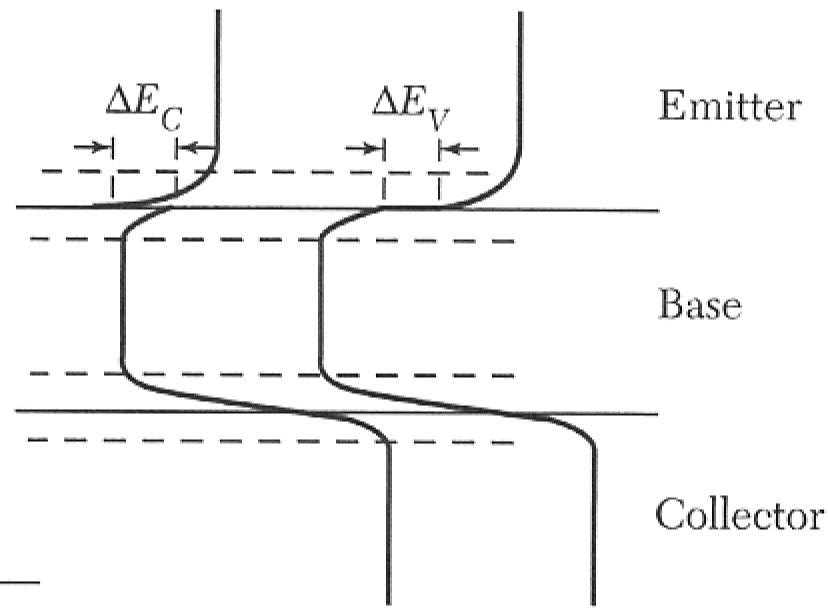
Technische Universität Graz

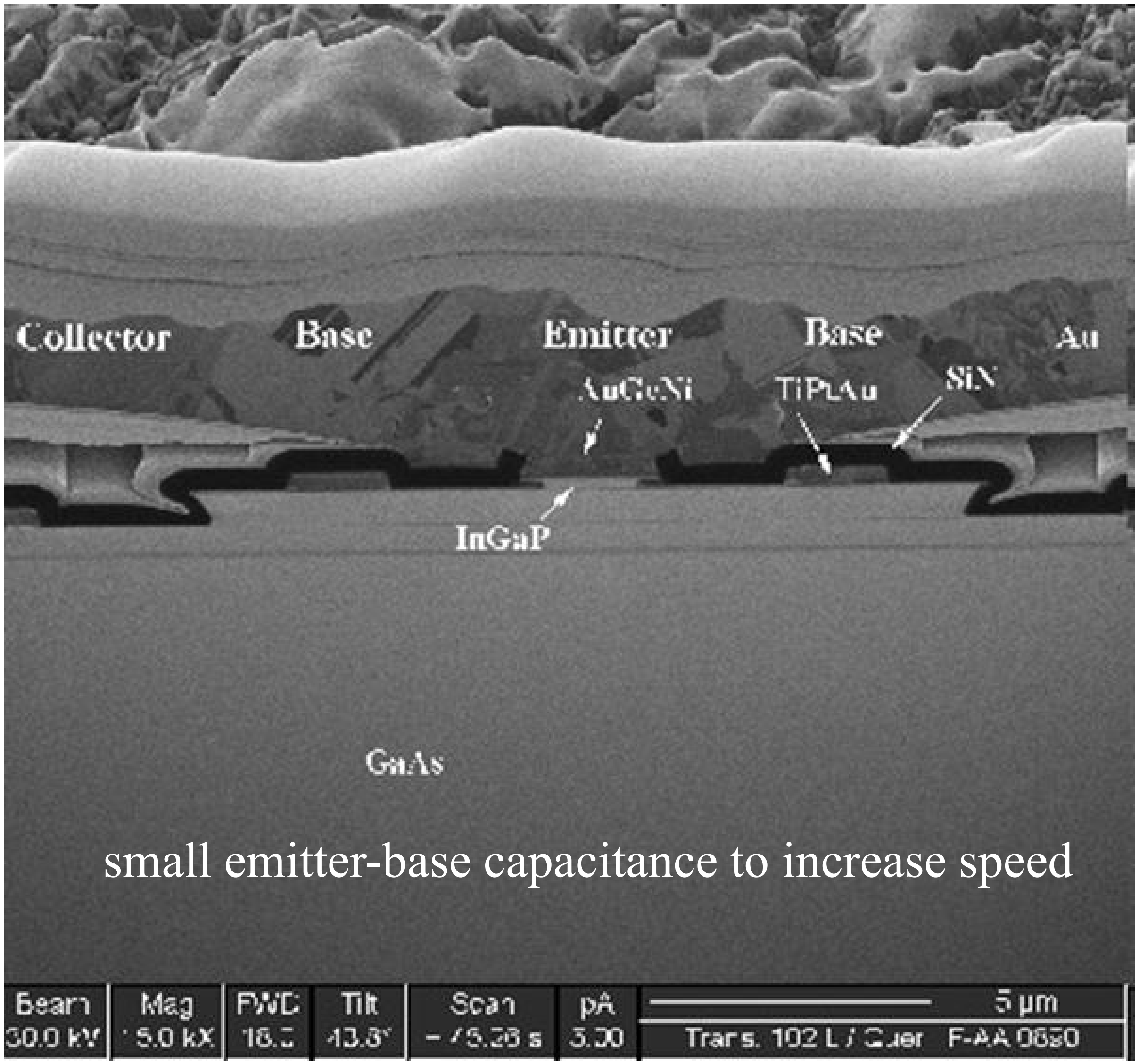
Heterojunction bipolar transistors, thyristors, and Latch-up

Heterojunction bipolar transistors





Heterojunction bipolar transistor



small emitter-base capacitance to increase speed

HBT current gain

$$I_C = \beta I_B$$

$$\beta = \frac{\alpha}{1-\alpha} \approx \frac{n_{B0}}{p_{E0}} \qquad \text{(npn)}$$

Higher doping in the emitter makes the minority carrier concentration lower in the emitter.

$$n_{B0} = \frac{n_i^2}{N_A} = \frac{N_C N_V \exp(-E_{gB}/k_B T)}{N_A}$$

$$p_{E0} = \frac{n_i^2}{N_D} = \frac{N_C' N_V' \exp(-E_{gE}/k_B T)}{N_D}$$

If the emitter and the base have different band gaps

$$\beta = \frac{N_E}{N_B} \frac{N_c N_v}{N_c' N_v'} \exp\left(\frac{\Delta E_g}{k_B T}\right) \sim 100000$$

HBT current gain

A HBT has an emitter bandgap of 1.62 and a base bandgap of 1.42.
A BJT has an emitter bandgap of 1.42 and a base bandgap of 1.42.
Both have an emitter doping of 10^{18} cm^{-3} and a base doping of 10^{15}cm^{-3}.
How much larger is the gain in the HBT?

$$\frac{\beta(\mathrm{HBT})}{\beta(\mathrm{BJT})} = \exp\left(\frac{\Delta E_g}{k_B T}\right) = \exp\left(\frac{1.62 - 1.42}{0.0259}\right) = 2257$$

HBT

Trade off gain for higher speed

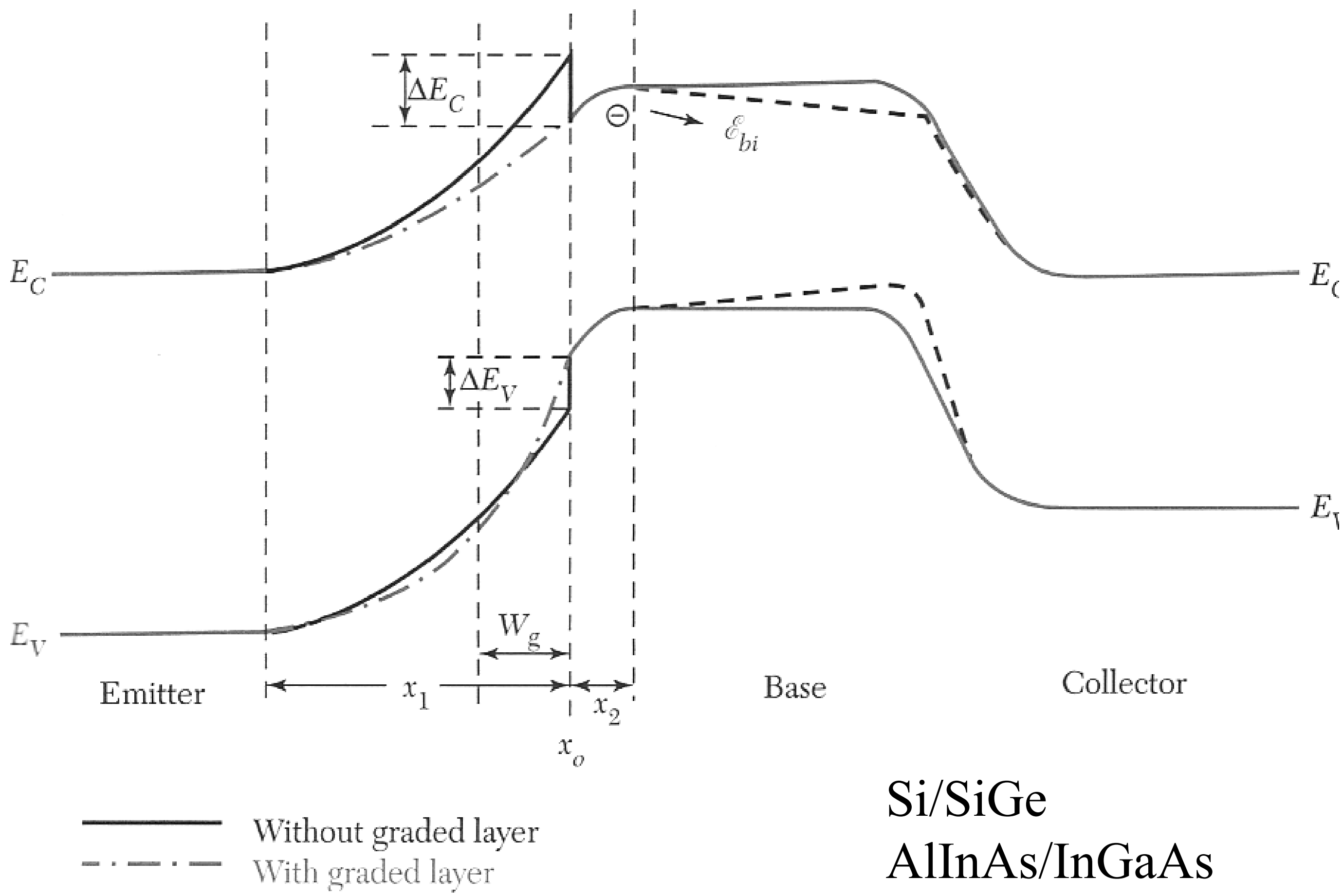
Higher base doping

- lower base resistance
- reduced Early effect
- less trouble with punch through
- base can be made thinner -> faster transistors

Because of higher base doping, a higher collector doping is possible without punch through

- lower collector resistance

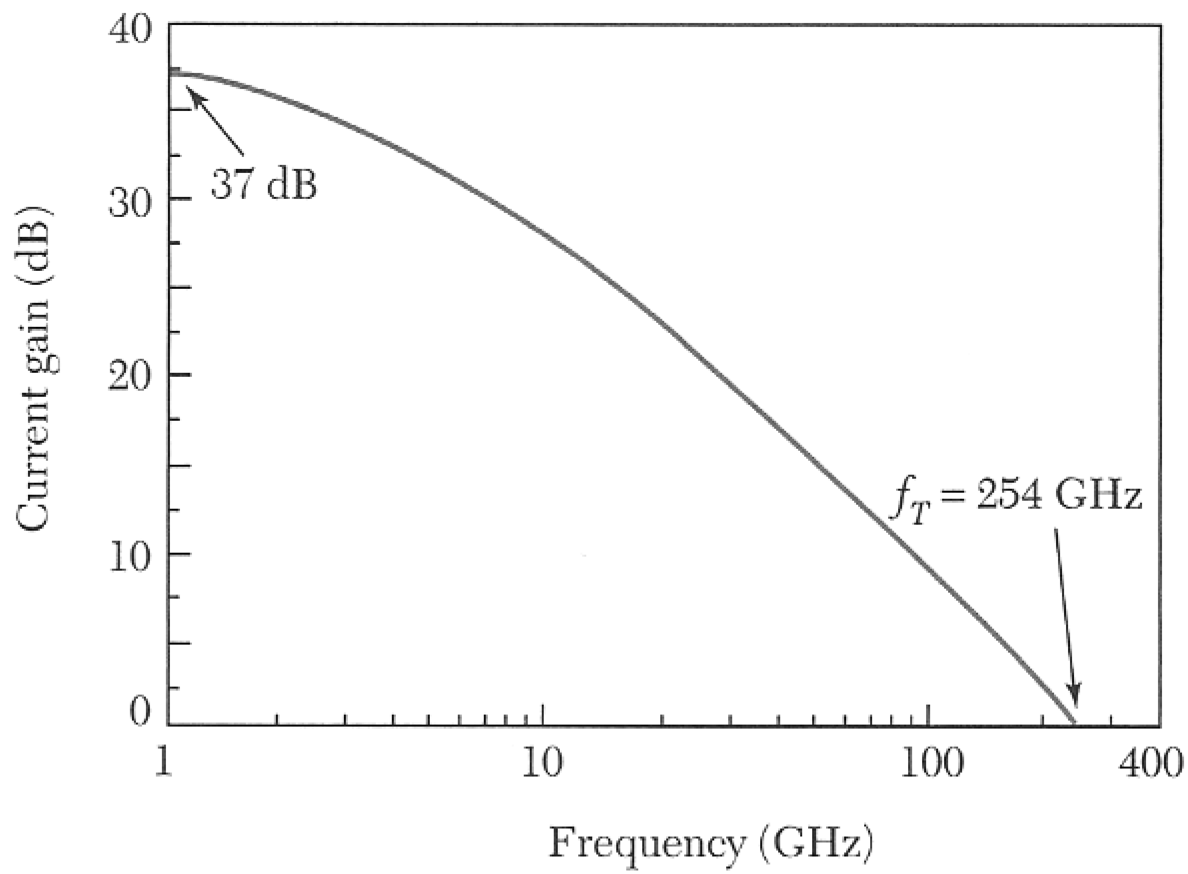
HBT current gain



Si/SiGe
AlInAs/InGaAs

band discontinuity reduces emitter efficiency
Graded layer emitter and base improve performance

Heterojunction bipolar transistors



Fastest InP/InGaAs HBT's have an f_T of 710 GHz.

Higher doping in the base allows for a thinner base without punch through and lower base resistance and thus higher frequency operation

Microwave engineering

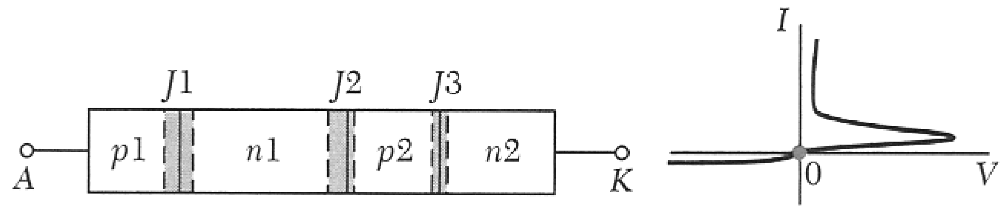
Electronics: $L \ll \lambda$ $f <\sim 10$ GHz

Microwave: $\lambda < L$ 10 GHz $< f <$ 1 THz

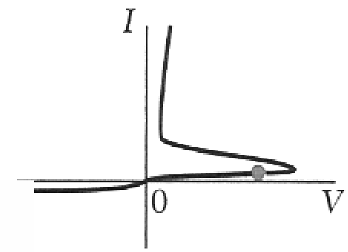
TeraHertz: $\lambda \ll L$ 1 THz $< f <$ 100 THz

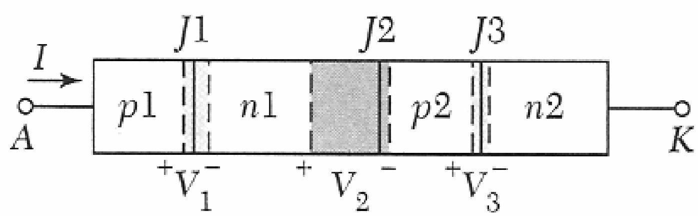
Optics: $\lambda \ll L$ 100 THz

Thyristors

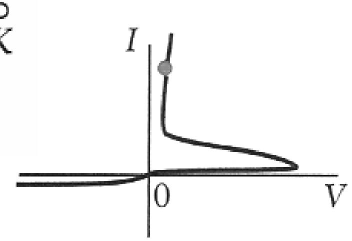


Forward blocking

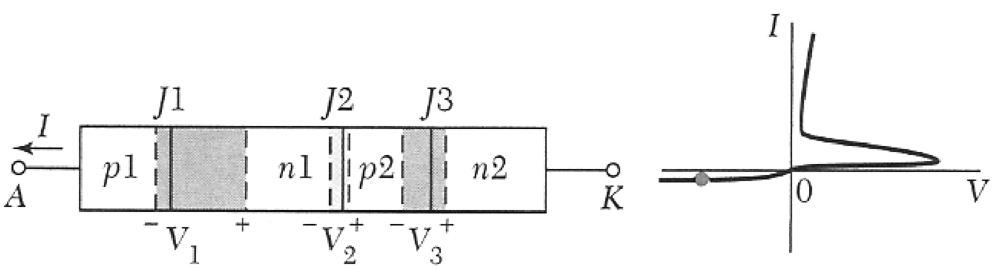




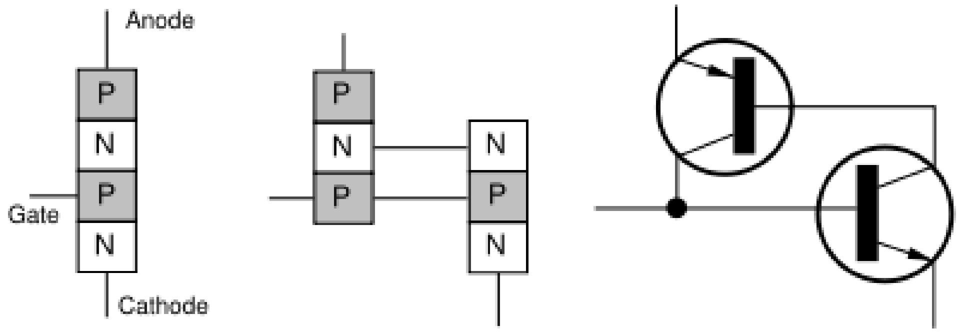
Forward conducting



Reverse blocking



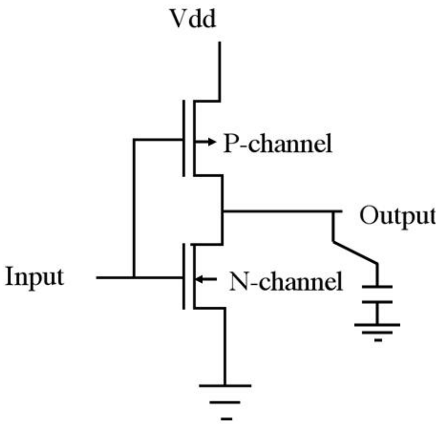
Thyristors

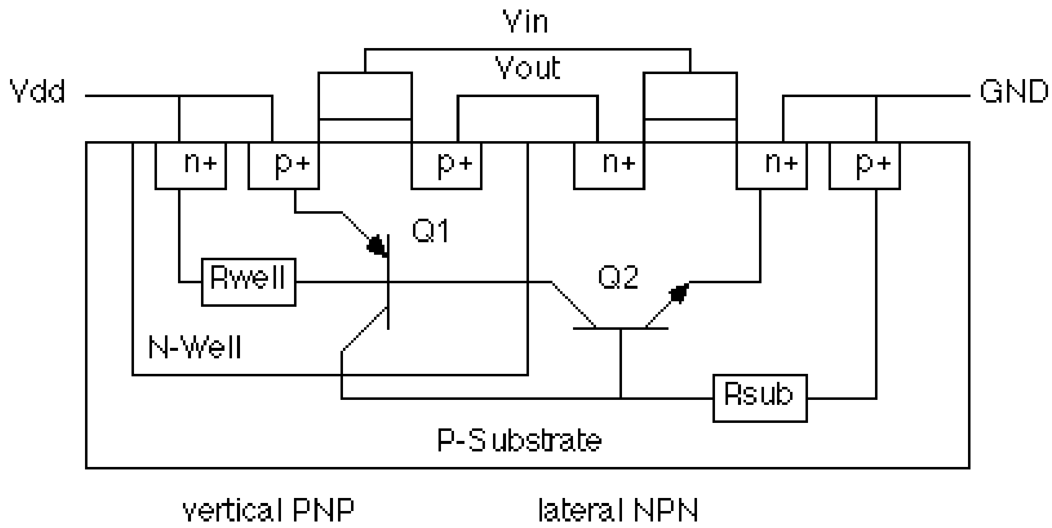


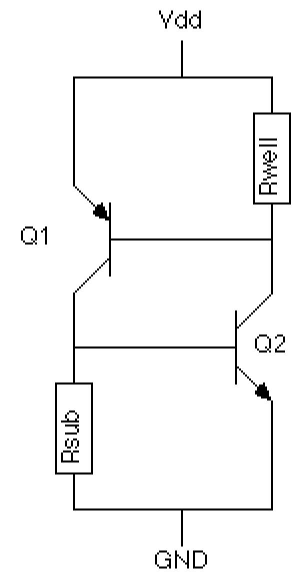
$\beta_1 * \beta_2 > 1$

Used for switching high currents or voltages

Latch-up



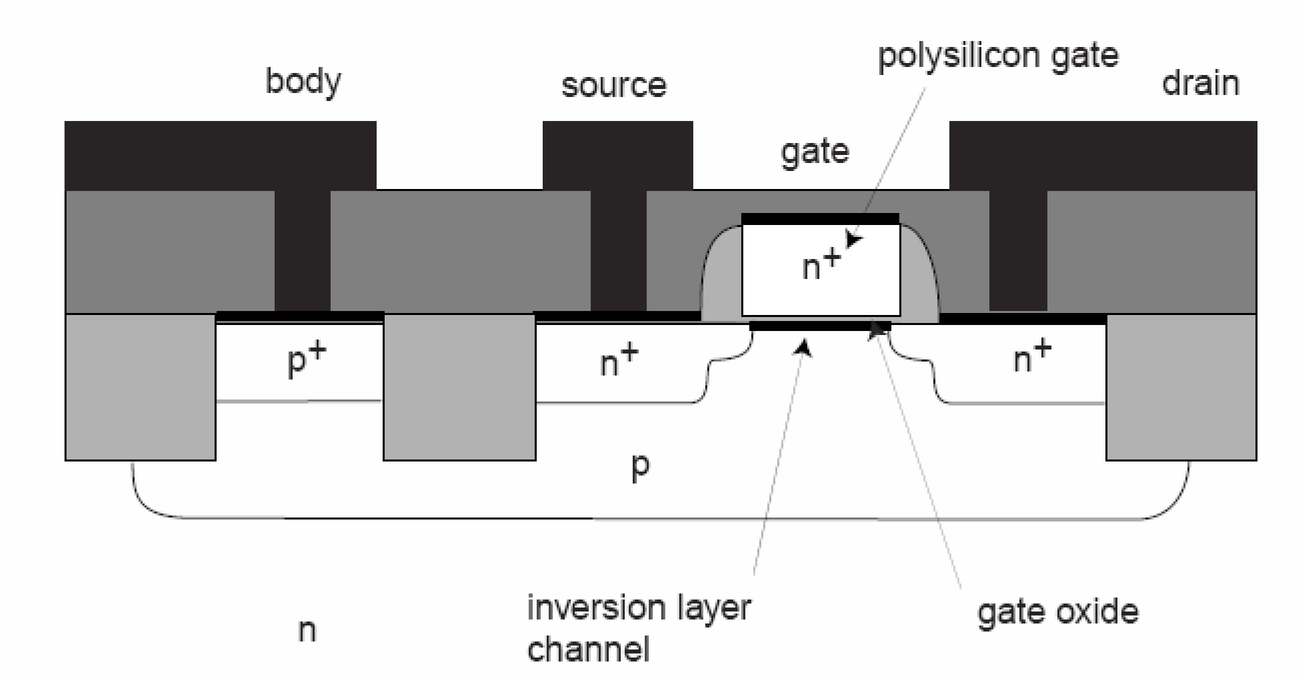




Both BJT's conduct, creating a low resistance path between V_{dd} and GND. The product of the gains of the two transistors in the feedback loop, is greater than one. The result of latchup is at the minimum a circuit malfunction, and in the worst case, the destruction of the device.

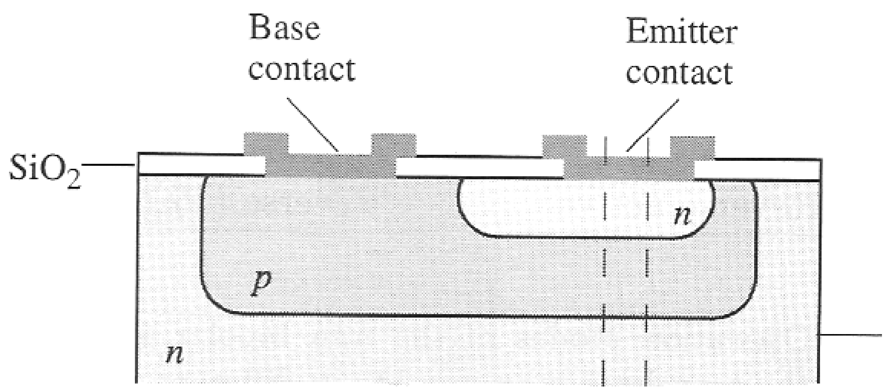
http://www.ece.drexel.edu/courses/ECE-E431/latch-up/latch-up.html

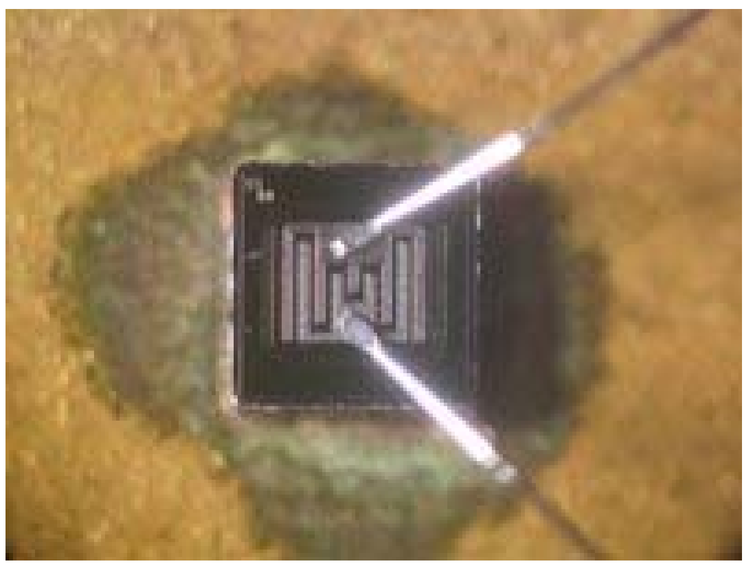
Subthreshold current

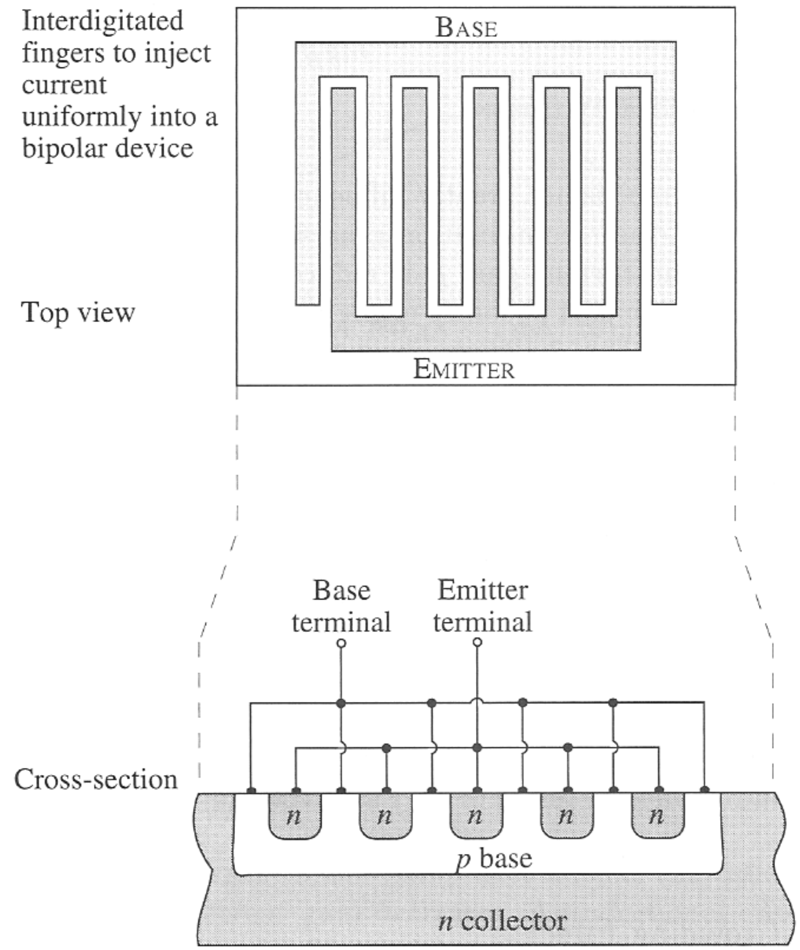


If the p-concentration in the channel is low, electrons emitted into the channel by the forward biased junction diffuse across the channel without recombining.

Interdigitated contacts in power transistors

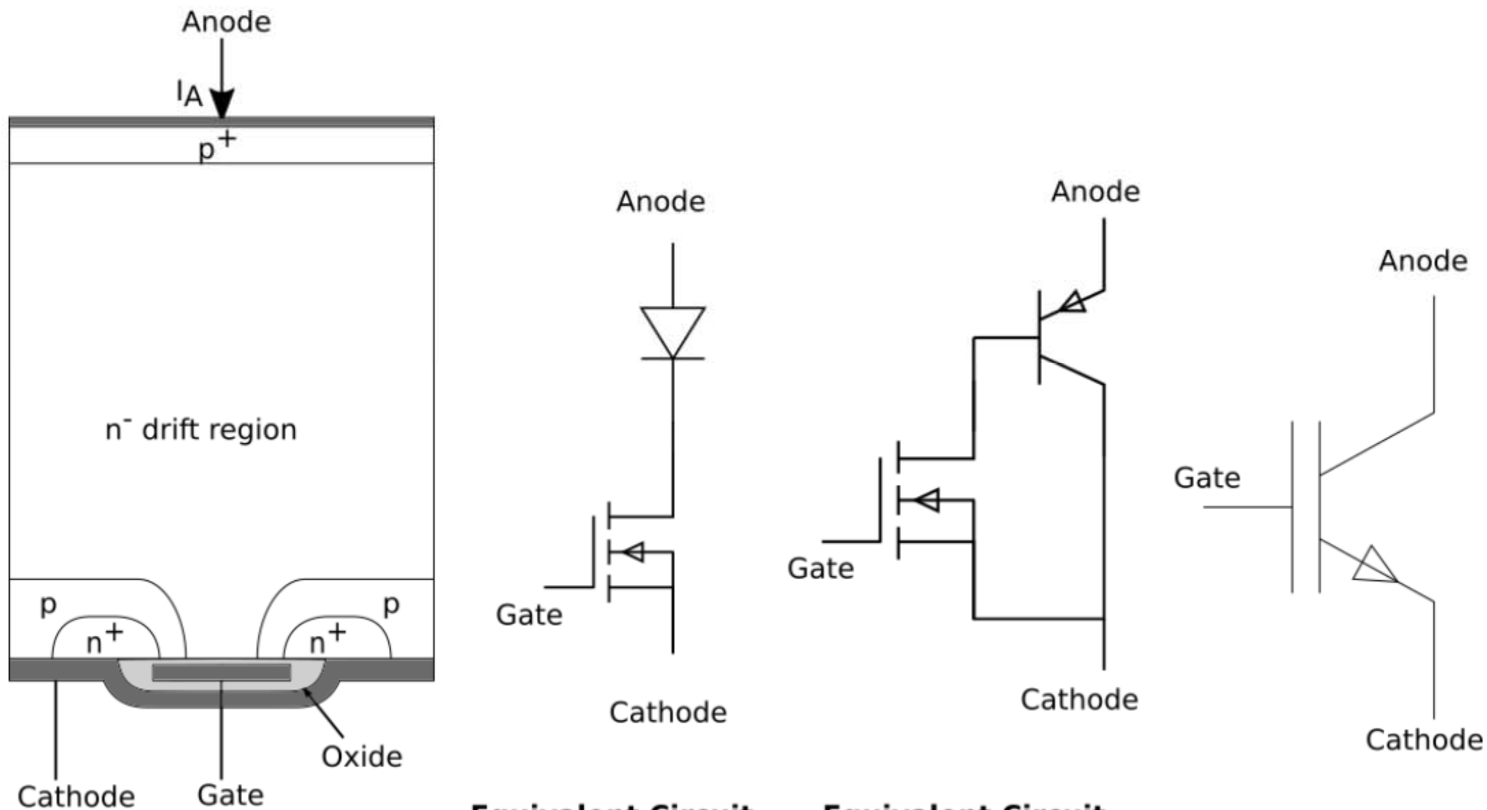






IGBT - Insulated Gate Bipolar Transistor

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).

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

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

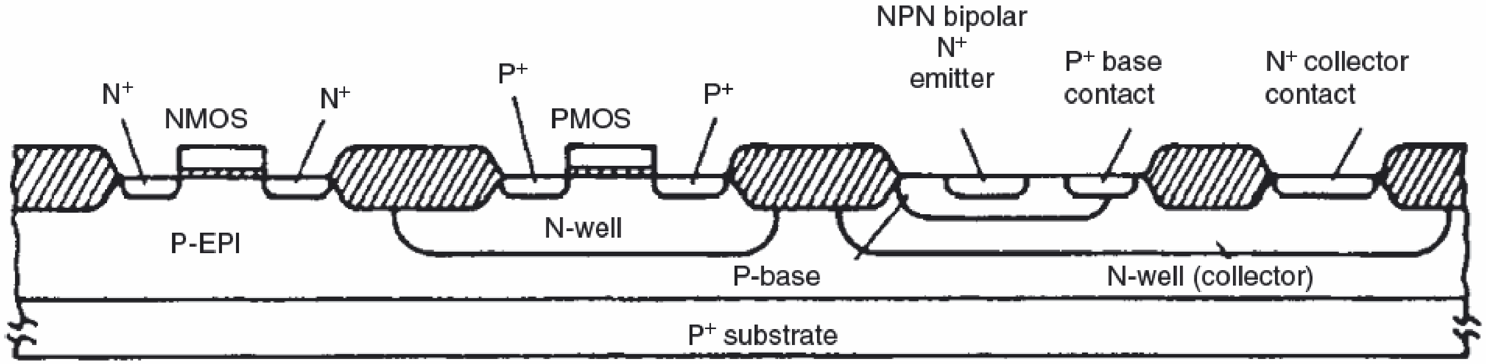
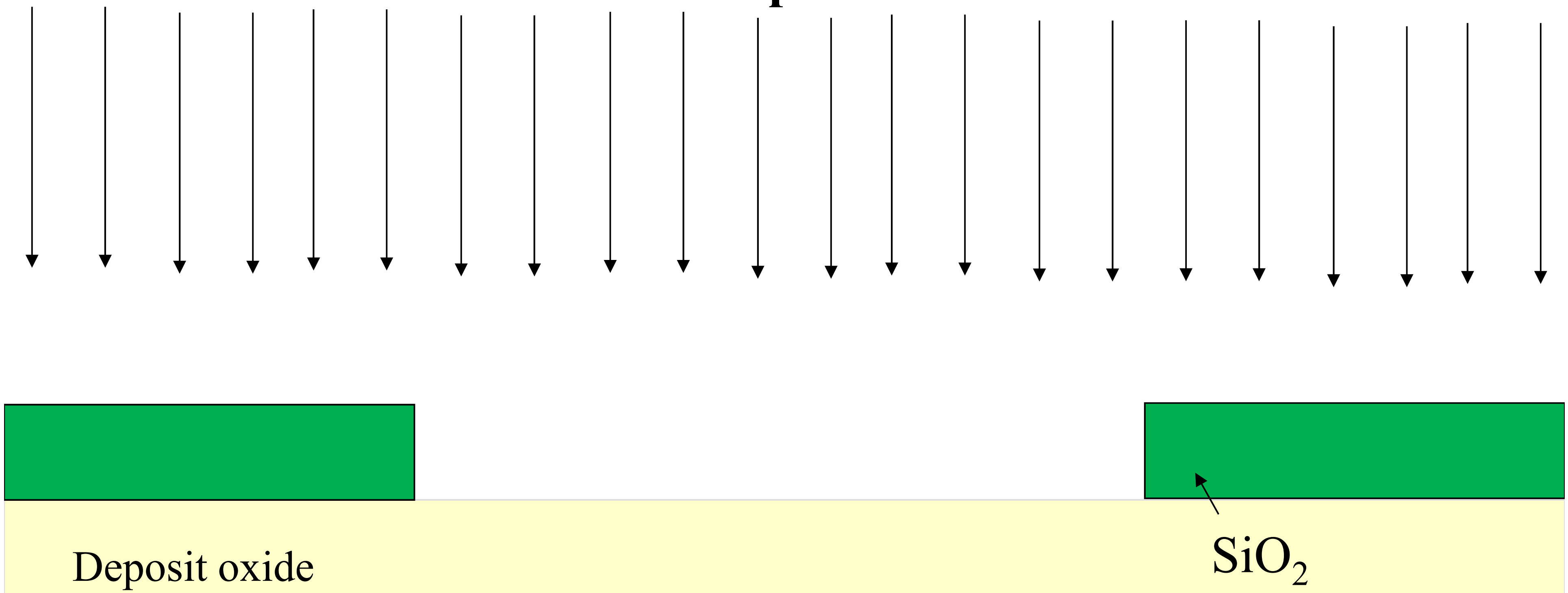


Figure 27.6 Simple BiCMOS technology: triple diffused-type bipolar transistor added to a CMOS process with minimal extra steps: only p-base diffusion mask is added to CMOS process flow. Reproduced from Alvarez (1989) by permission of Kluwer

Fransila

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

Implant

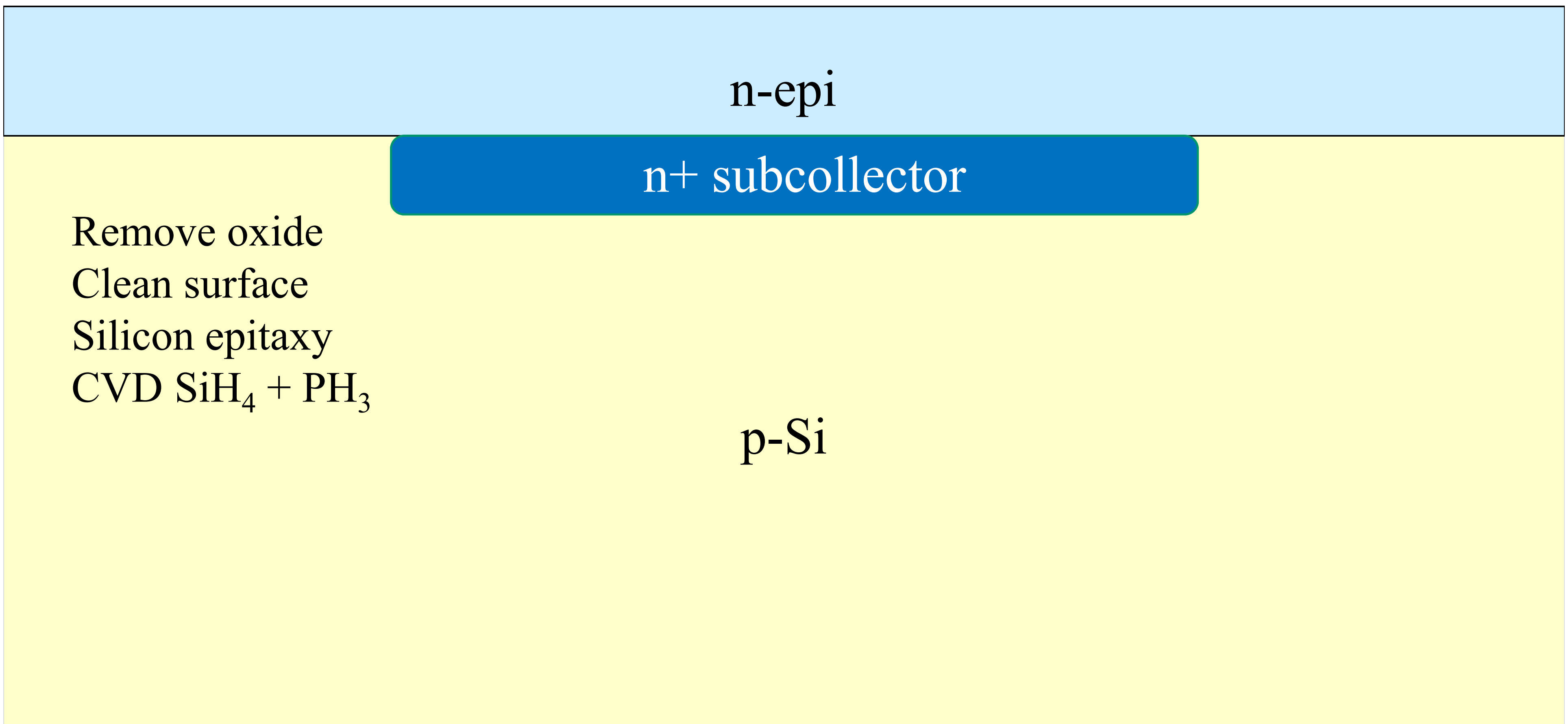


Deposit oxide
Spin resist
Expose
Develop
Etch Oxide
Strip resist
Implant subcollector n+

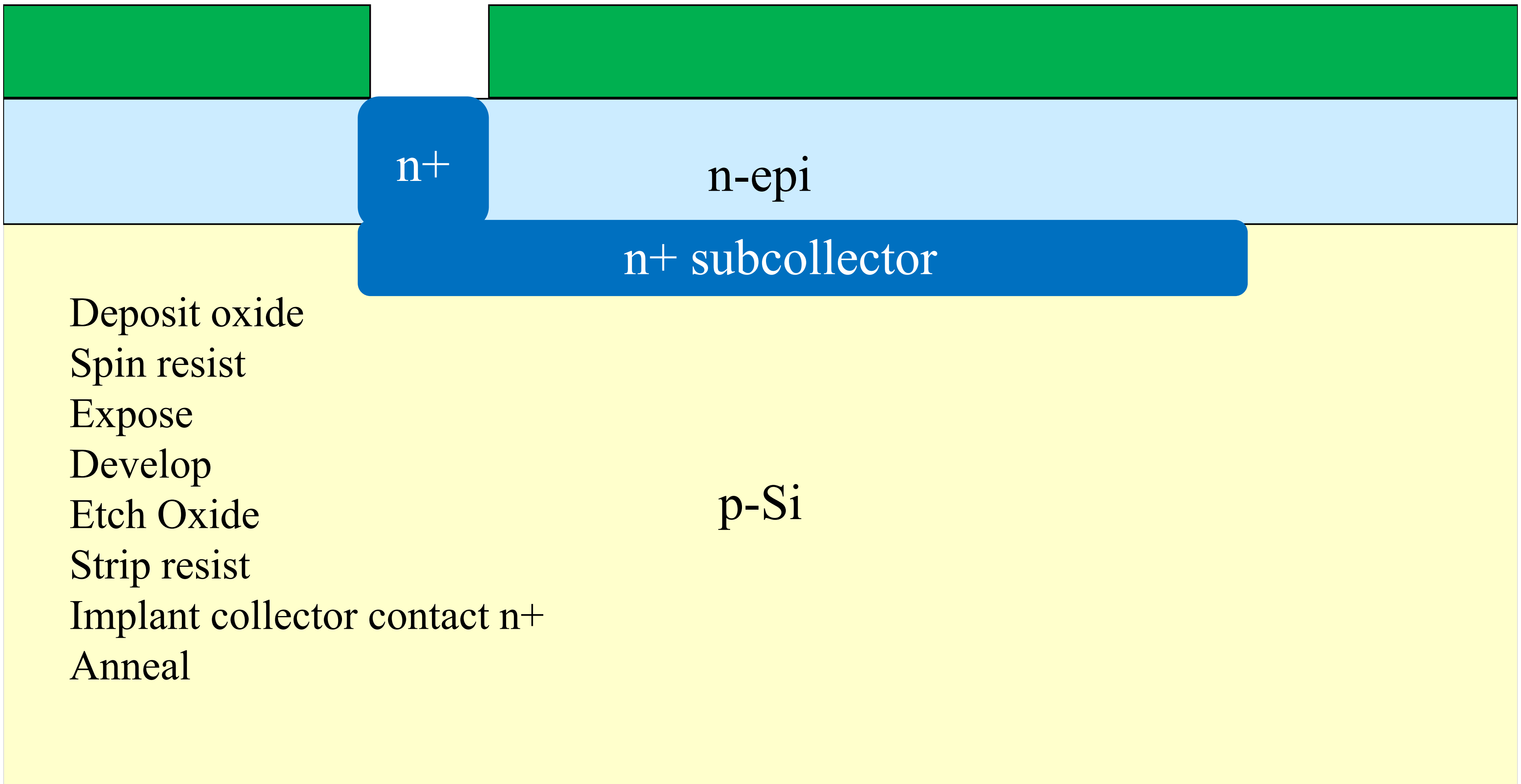
p-Si

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

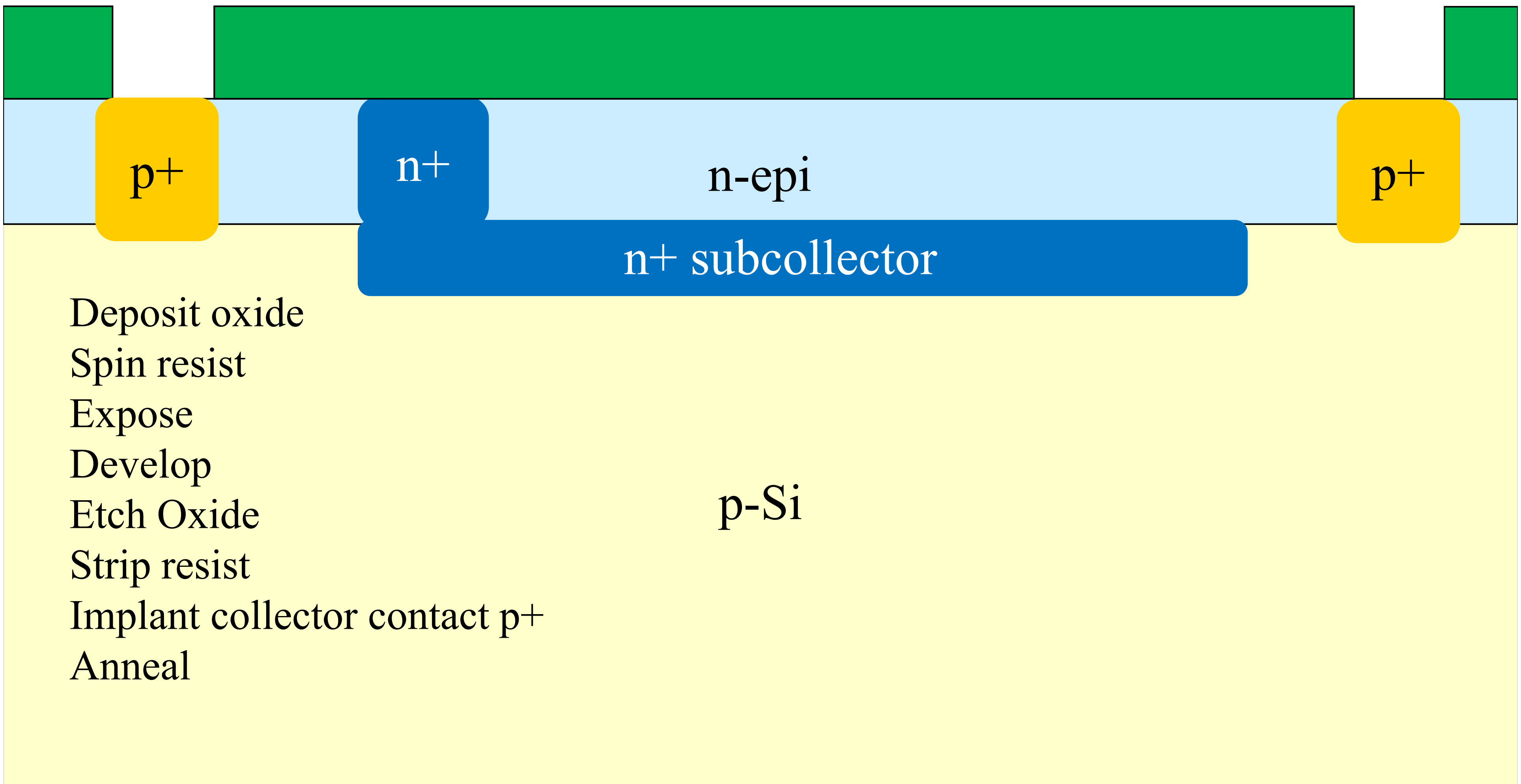
Epi-growth


n-epi
n+ subcollector
Remove oxide
Clean surface
Silicon epitaxy
CVD $SiH_4 + PH_3$
p-Si

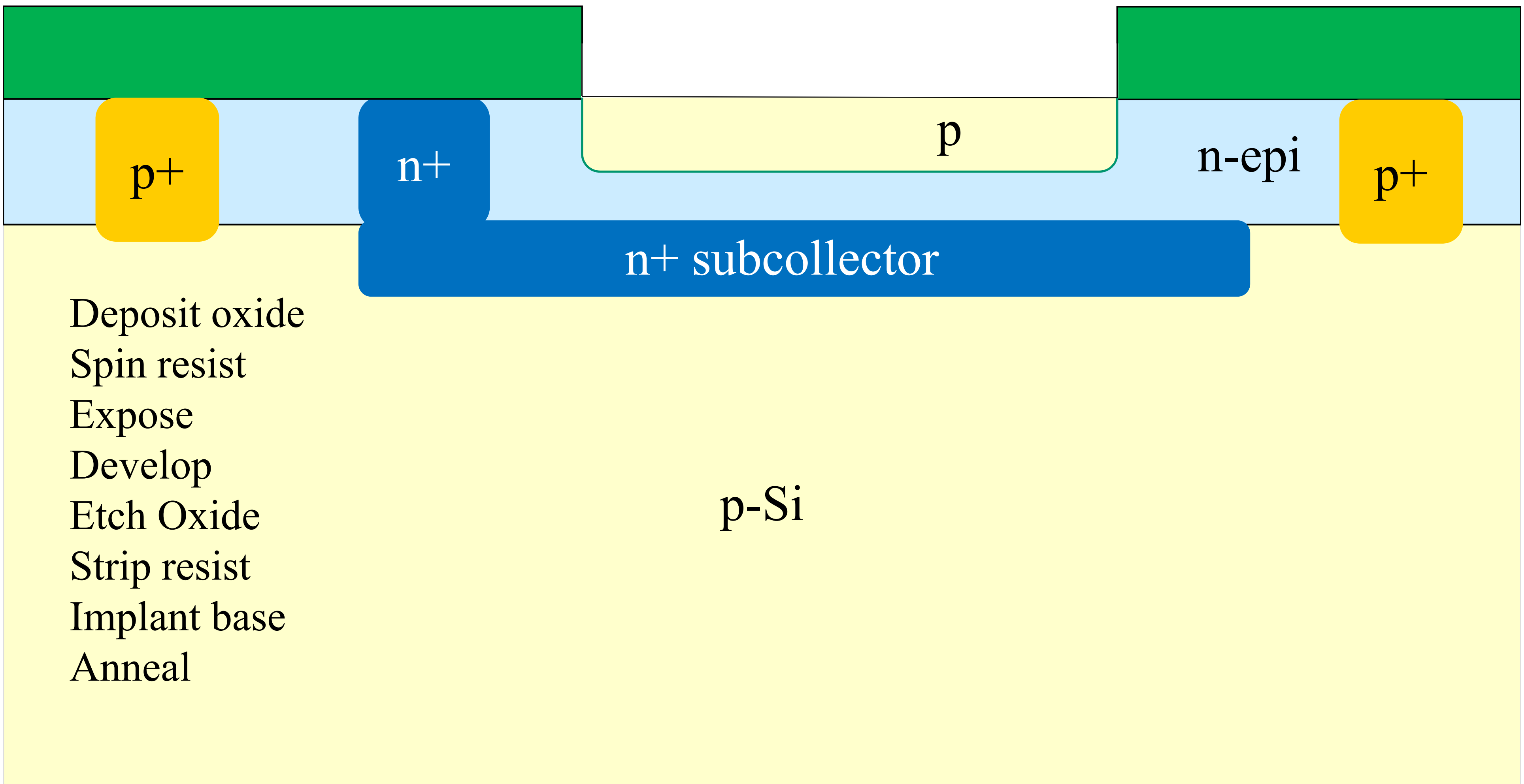
Collector Contact



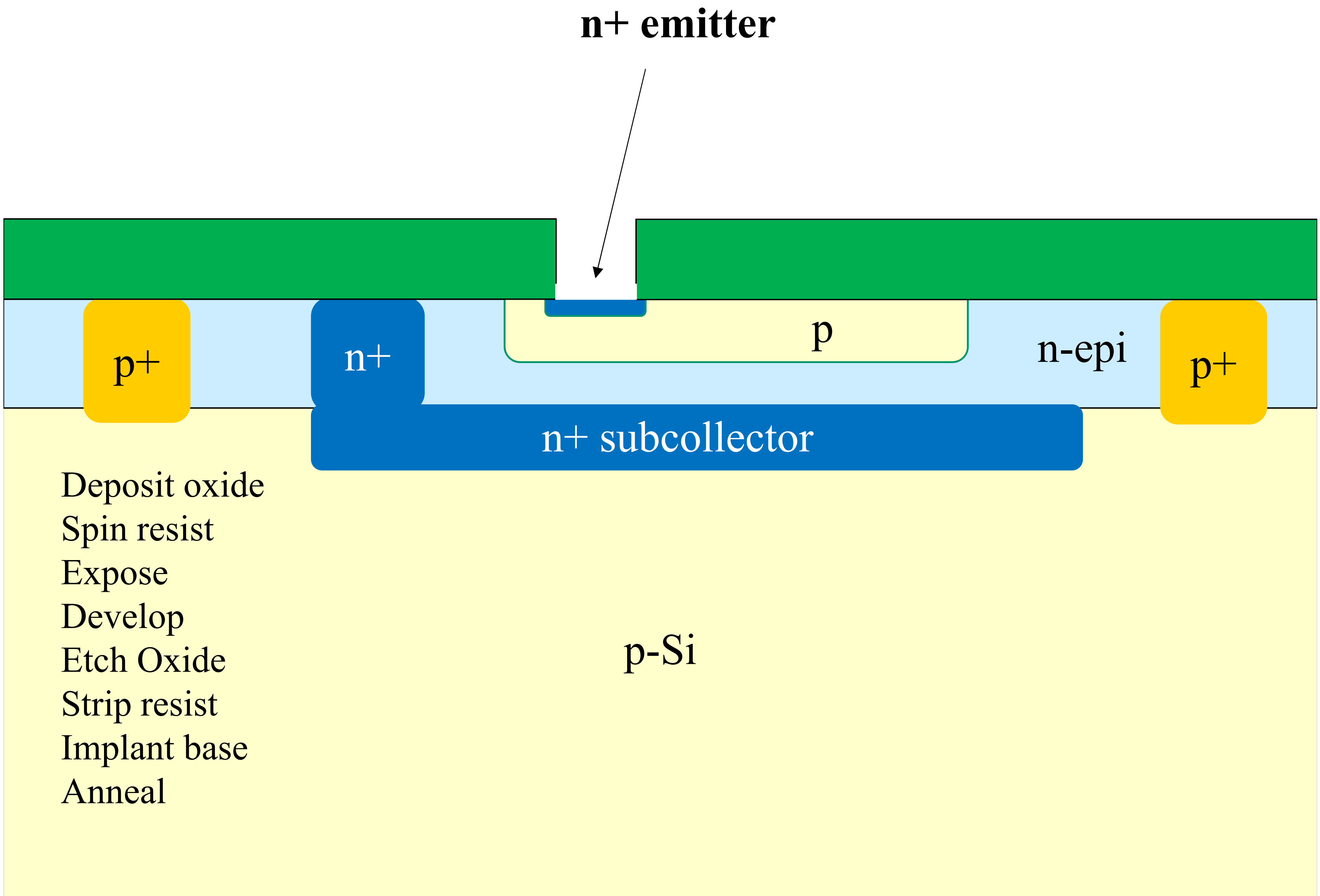
Guard ring


p+
n+
n-epi
p+
n+ subcollector
Deposit oxide
Spin resist
Expose
Develop
Etch Oxide
Strip resist
Implant collector contact p+
Anneal
p-Si

p-well



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


n+ emitter
p+
n+
p
n-epi
p+
n+ subcollector
Deposit oxide
Spin resist
Expose
Develop
Etch Oxide
Strip resist
Implant base
Anneal
p-Si