Lecture/Laboratory #3

Outline:

1. Review RC, LC filters and some important points of previous lecture
2. Discuss some laboratory problems/works
3. Rectification
4. Ckts with bipolar transistors
   - Voltage amplifier
   - Voltage conversion
   - Transistor switch, current source
   - Common emitter ampl. And differ. Ampl.
5. **Laboratory works**

   (a) Curve tracers for LC filters

<u>RC Differentiators</u>

RC differentiator: the same circuit as high-pass filter. Such circuit can be considered as high-pass filter of differentiator depending on domain: <u>frequency domain</u> $\Rightarrow$ filter, <u>time domain</u> $\Rightarrow$ differentiator.

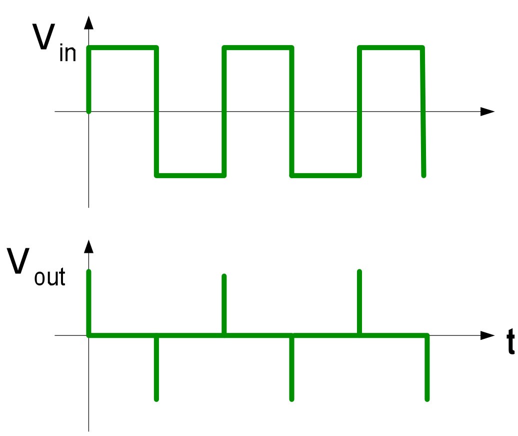
$$I = C\frac{d}{dt}(V_{in} - V_{out}) = V_{out}/R$$

Voltage across C

If <u>R</u> and <u>C</u> are small, such that $dV_{out}/dt << dV_{in}/dt$, then

$$C\frac{dV_{in}}{dt} \approx \frac{V_{out}}{R} \quad \Rightarrow \quad \underbrace{V_{out}(t) = RC\frac{dV_{in}(t)}{dt}}$$

Output ~ to the rate of change of input



Relation between high-pass filter and differentiator?

Differentiator: $V_{out} << V_{in}$

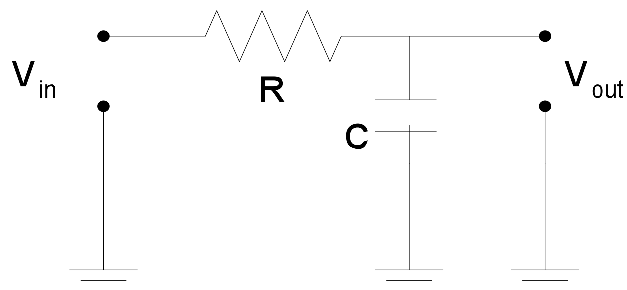
From frequency response of h – p filter $\omega << \omega_{3dB}$ $\Rightarrow$

$$\underline{\omega << \frac{1}{RC}} \quad or \quad \underline{R << \frac{1}{\omega C}}$$

Low-pass Filters

By interchanging R and C in previous circuit we can get opposite frequency behavior in a RC filter.

Z_{tot} for both ckts (high- and low-pass) is the same, hence:



$$V_{out} = V_{in} \frac{1/\omega C}{\left(R^2 + 1/\omega^2 C^2\right)^{1/2}} =$$

Low-pass filter

(rejecting high ω)

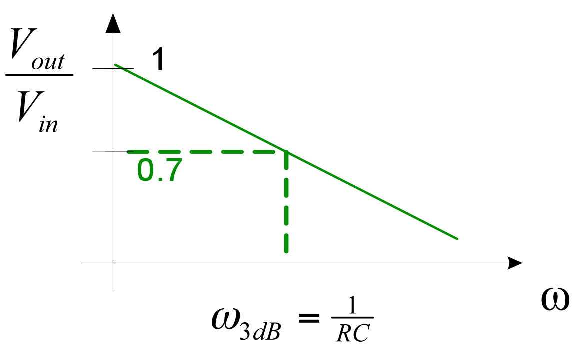
$$= V_{in}\left[\ 1 + (2\pi\nu RC)^2\ \right]^{-1/2}$$

and

$$\omega_{3dB} = \frac{1}{RC}$$

For $\omega < \omega_{3dB}$ → **low-pass filter**

For $\omega > \omega_{3dB}$ → $V_{out} / V_{in} \sim \omega^{-1}$



Integrators

RC integrator: the same ckt as low-pass filter .

As in the case of high-pass filter/differentiator the integrator/low-pass filter ckt can be considered as low-pass filter in frequency domain or integrator in time domain.

In time domain voltage across R is $V_{in} - V_{out}$,

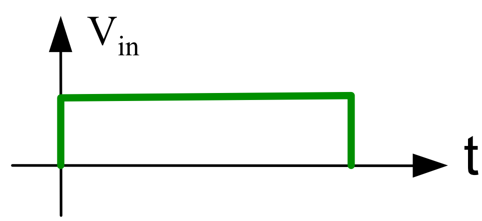
$$I = C\frac{dV_{out}}{dt} = \frac{V_{in} - V_{out}}{R}$$

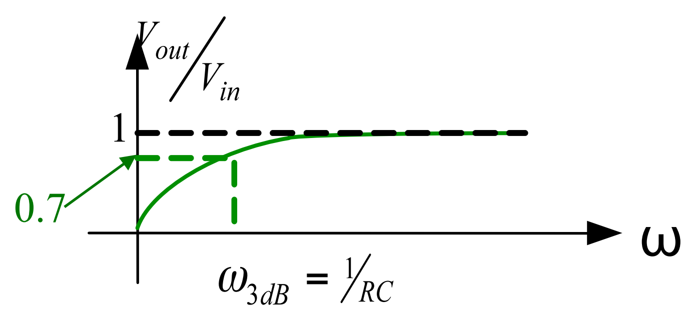
For $Z_R >> Z_C$ (RC large) $\Rightarrow$ $V_{out} << V_{in}$, hence

$$C\frac{dV_{out}}{dt} \approx \frac{V_{in}}{R} \Rightarrow \underbrace{V_{out}(t) = \frac{1}{RC}\int_0^t V_{in}(t)dt + const.}_{\text{Integrator, when } RC >> 1/\omega}$$

$$\omega_{3dB} = \frac{1}{RC} \quad ;$$

$$\nu_{3dB} = \frac{1}{2\pi RC}$$





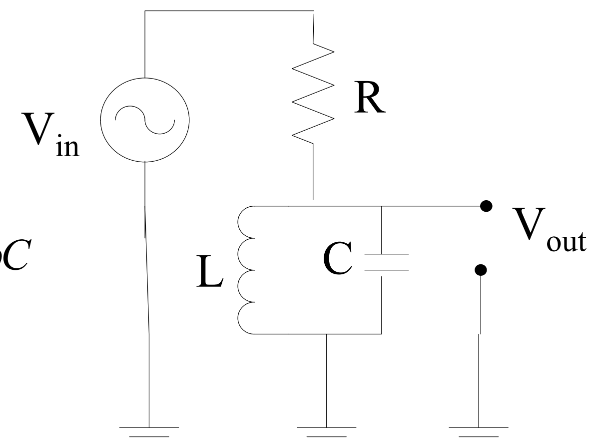
Integrators (cont.)

Inductor L in combination with R can also be used as low- and high-pass filters (RL – filters). However, RC filters are more convenient and less expensive to use.

Resonant Circuits

"Active" filter → combination of capacitor with inductor

Parallel LC filter



$$\frac{1}{\mathbf{Z}_{LC}} = \frac{1}{\mathbf{Z}_L} + \frac{1}{\mathbf{Z}_C} = \frac{1}{i\omega L} + i\omega C$$

$$\mathbf{Z}_{LC} = \frac{i}{1/\omega L - \omega C}$$

$$\mathbf{Z}_L = i\omega L \ , \quad \mathbf{Z}_C = \frac{1}{i\omega C}$$

for

$$\omega_0 = \frac{1}{\sqrt{LC}} \rightarrow \mathbf{Z}_{LC} = \infty$$

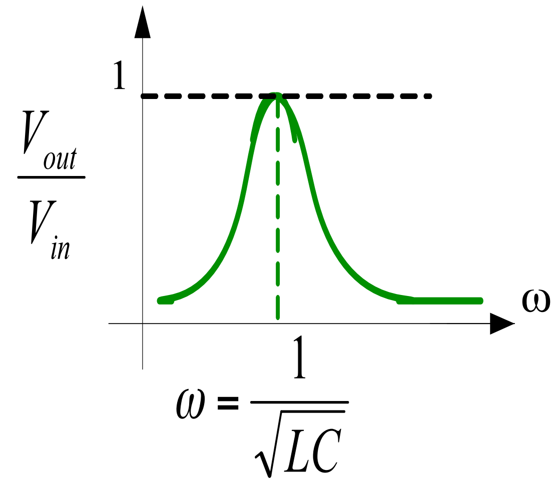
Divider with

$$V_{out} = V_{in} \frac{\mathbf{Z}_{LC}}{\mathbf{Z}_{LC} + R}$$

Resonant Circuits (cont.)

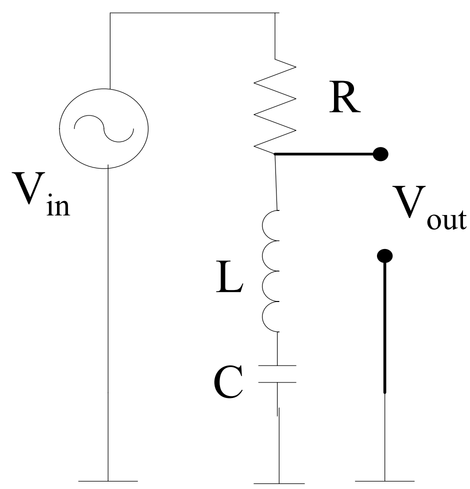
for

$$Z_{LC} = \infty \Rightarrow V_{out}/V_{in} = 1$$



Series LC filter

$$\mathbf{Z}_{LC} = i\omega L + \frac{1}{i\omega C} = i\left(\omega L - \frac{1}{\omega C}\right)$$

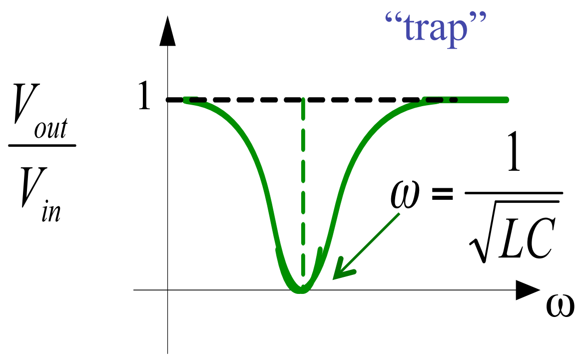


For $\omega_0 = \frac{1}{\sqrt{LC}} \Rightarrow \mathbf{Z}_{LC} = 0$

$\Downarrow$

$V_{out} = 0$

"trap"



At ω_0 signal short to ground

In Laboratory:

Curve tracers for LC "active" filters

(a) Parallel LC filter

(b) Series LC filter

Look for resonances (Change L,C,R and observe how sharp resonances could be)

Rectification

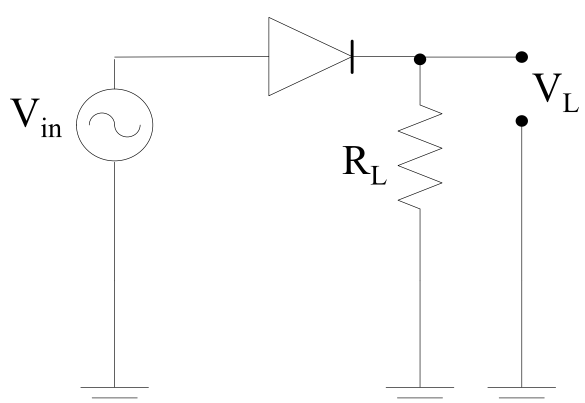
Rectifier changes AC current/voltage to DC. Diode play the most important role (it is most important function of diode)

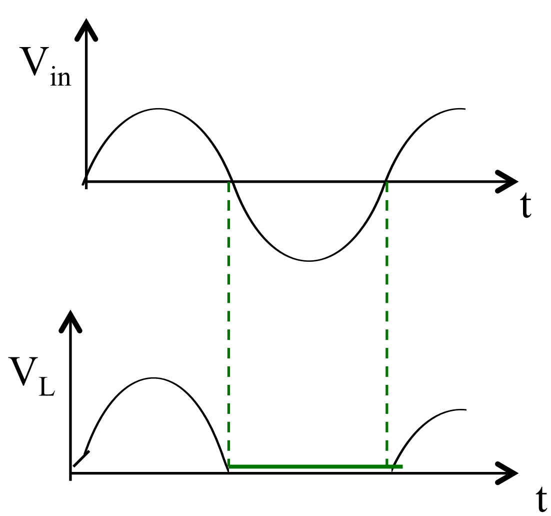
Two things about diodes:

(a) Diode doesn't obey Ohm's law (diode doesn't have resistance in common sense)

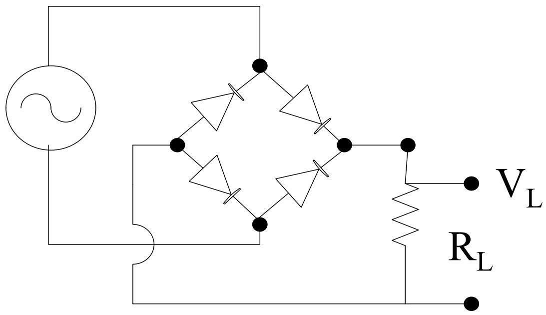
(b) Diode in ckt have no Thévenin's equivalent

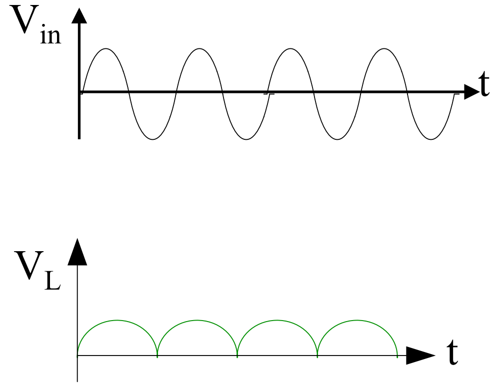
Half-wave rectifier



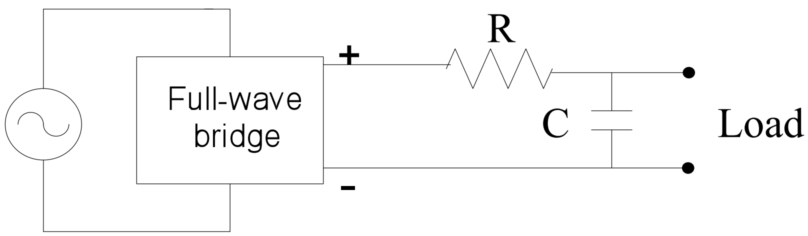


Full-wave bridge rectifier

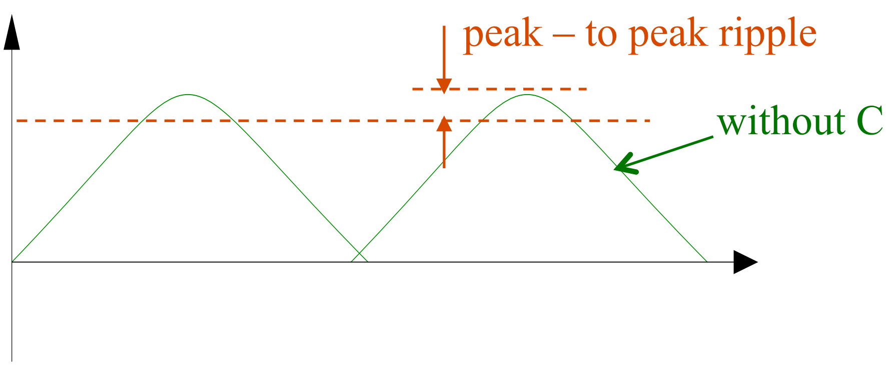




Filtering rectifier



$$R_{Load}C >> \frac{1}{\omega}$$



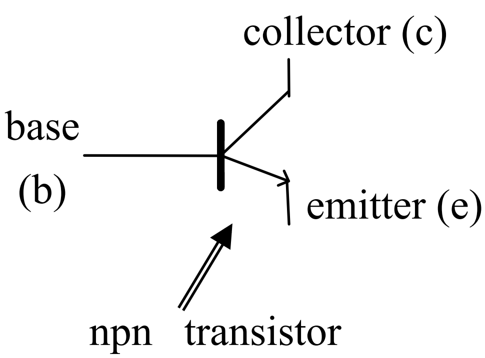
Introduction to Transistors

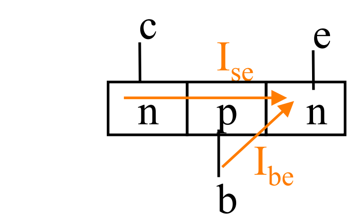
Transistor : 3 – terminal device

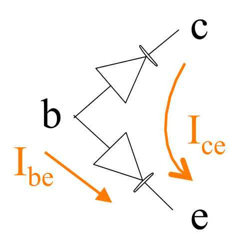
Two types of transistors: npn and pnp

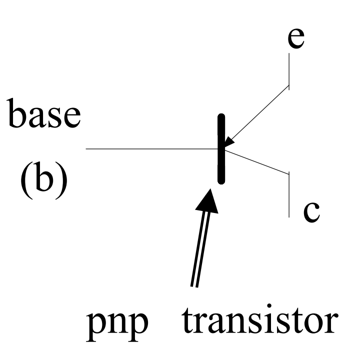
n – electron dominated

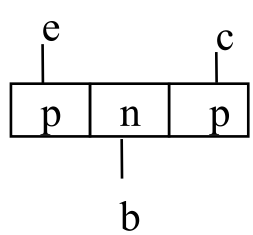
p – holes dominated

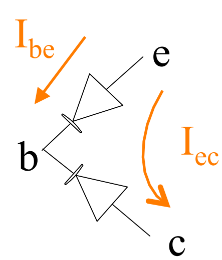












Semiconductors as Diodes

Semiconductor materials (Fig. A1)

(a) Single species of atoms (silicon, Si; Fermanium, Ge) (Table 1)

(b) Composed materials (e.g. Galium Arsenide, GaAs ⇒ III – V; Lead Sulfur, PbS ⇒ IV – VI) (Table 2)

Importance of Si as a component (lower leakage than Ge , abundance)

Energy Levels ⇒ Bands:

Valence Band, ⇒ Upper: E_V

Conduction Band ⇒ Lower: E_c

Bandgap, E_g

⇑

Most important parameter in semiconductor Physics.

Fig. A1. Typical range of resistivity (conductivities) for insulators, semiconductors, and conductors

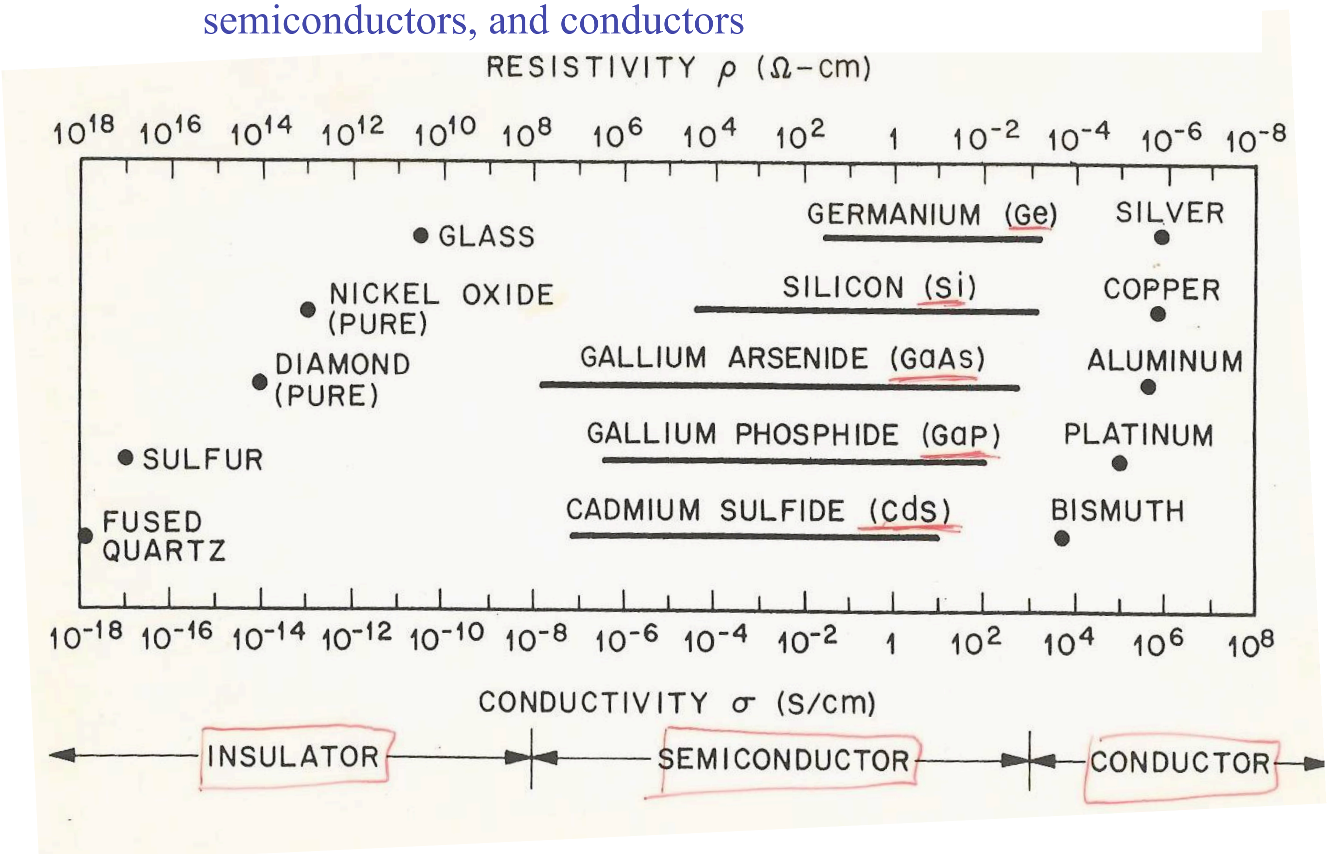


Table 1 Portion of the Periodic Table Related to Semiconductors

Period	Column II	III	IV	V	VI
2		B Boron	C Carbon	N Nitrogen	
3	Mg Magnesium	Al Aluminum	Si Silicon	P Phosphorus	S Sulfur
4	Zn Zinc	Ga Gallium	Ge Germanium	As Arsenic	Se Selenium
5	Cd Cadmium	In Indium	Sn Tin	Sb Antimony	Te Tellurium
6	Hg Mercury		Pb Lead		

Table 2 Element and Compound Semiconductors

Element	IV–IV Compounds	III–V Compounds	II–VI Compounds	IV–VI Compounds
Si	SiC	AlAs	CdS	PbS
Ge		AlSb	CdSe	PbTe
		BN	CdTe	
		GaAs	ZnS	
		GaP	ZnSe	
		GaSb	ZnTe	
		InAs		
		InP		
		InSb		

Fig. A2

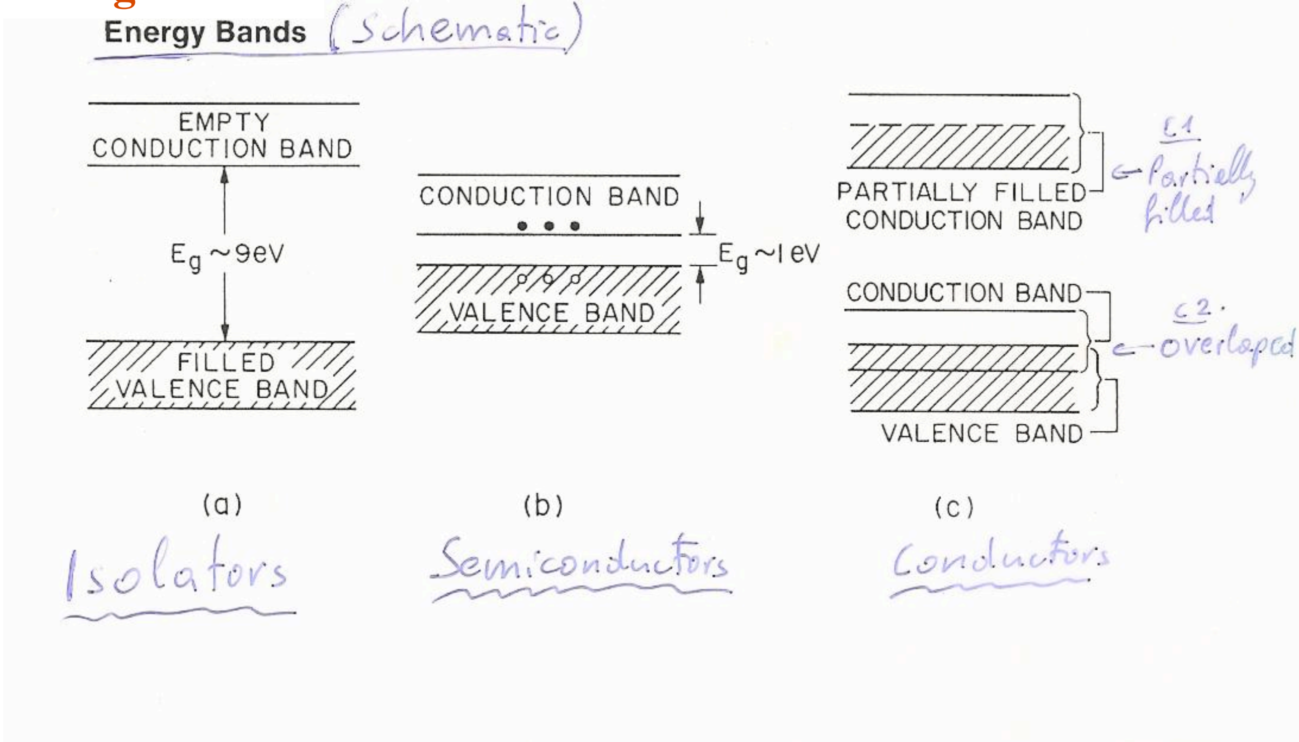
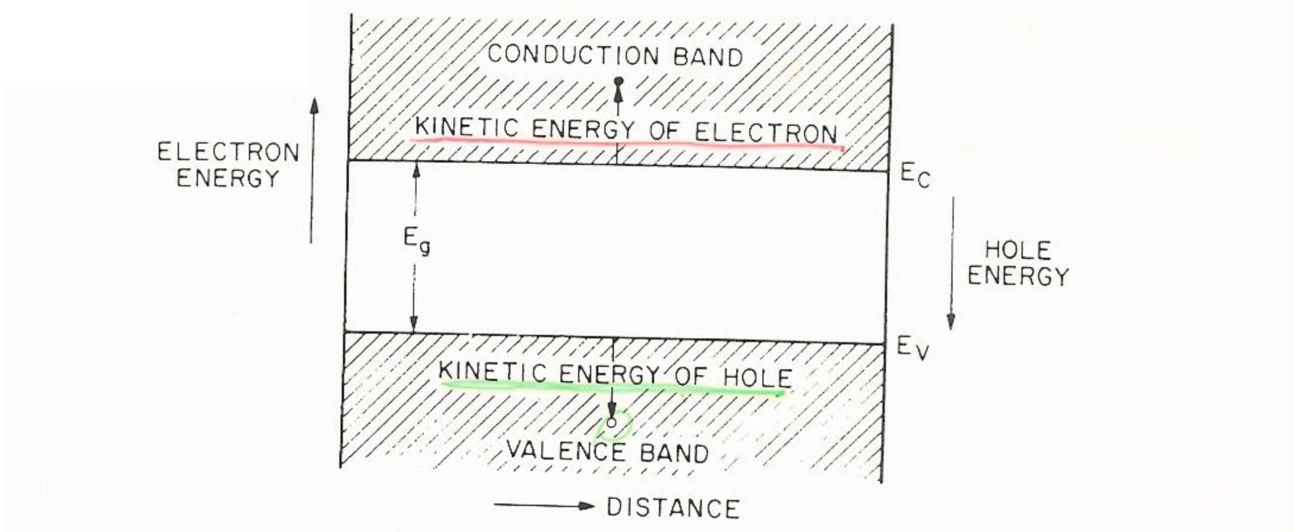


Fig. A3



Potential and kinetic energies in band representation

Semiconductors as Diodes (cont.)

Isolators $\Rightarrow$ Large bandgaps (e.g. SiO_2 : $E_g \sim 9$ eV)

$\Downarrow$

Empty conduction band $\Rightarrow$ no free electrons to carry current

Semiconductors $\Rightarrow$ Moderate bandgaps (e.g. Si : $E_g \sim 1.1$ eV
e.g. GaAs: $E_g \sim 1.4$ eV)

$\Downarrow$

Thermal energy (thermal vibrations) may move electrons to <u>conduction</u> <u>band</u> $\Rightarrow$ can move under E – field $\Rightarrow$ <u>current</u>

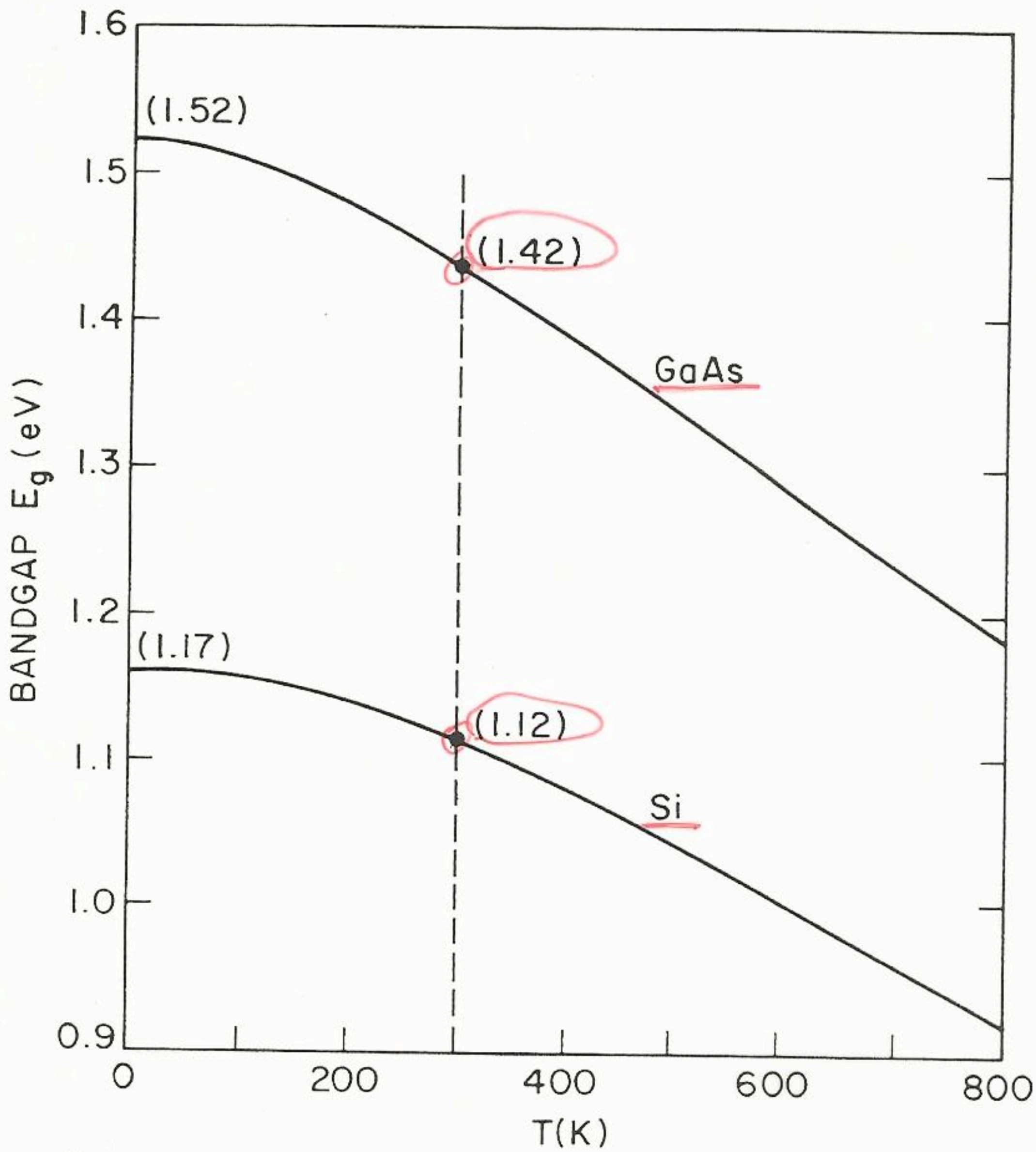
[minus electrons in <u>valence band</u> (holes)]

Conductors $\Rightarrow$ (1) Conduction band is partially filled

(2) Conduction and valence bands are overlapped $\Rightarrow$ <u>no bandgap</u>

current can rapidly occur

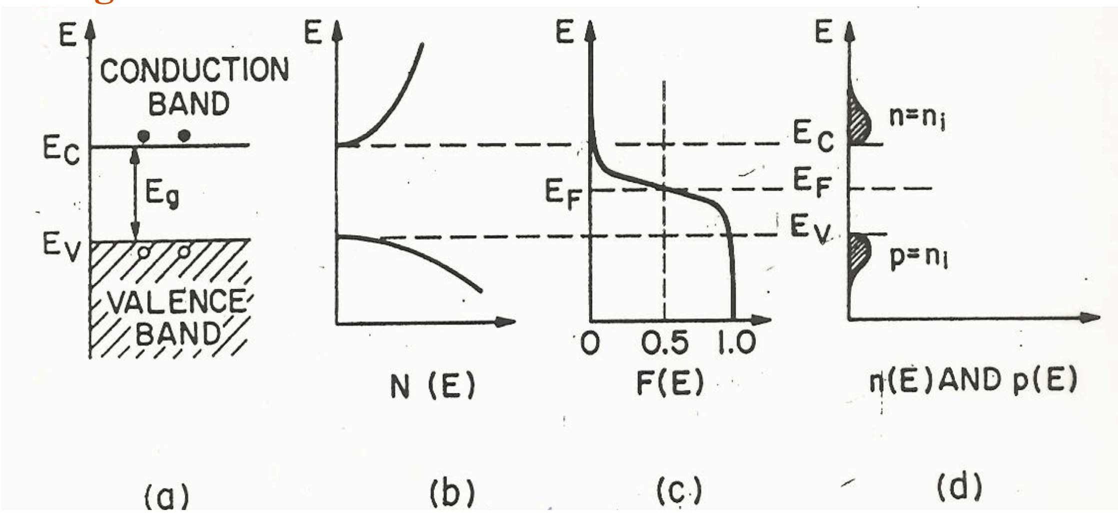
Fig. A4



Bandgaps of GaAs and Si as a function of temperature

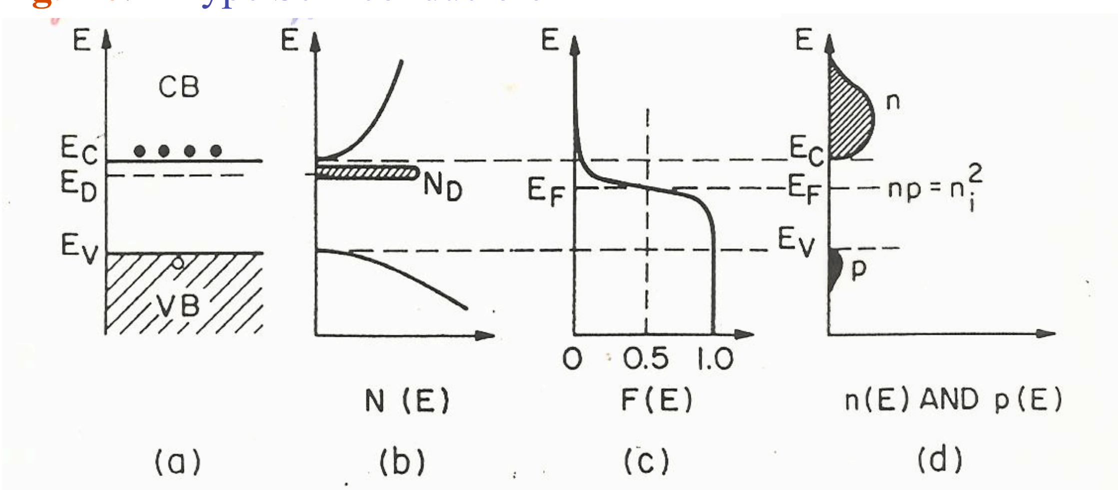
Intrinsic and n – type Semiconductors (or p – type)

Fig. A5. Intrinsic Semiconductor



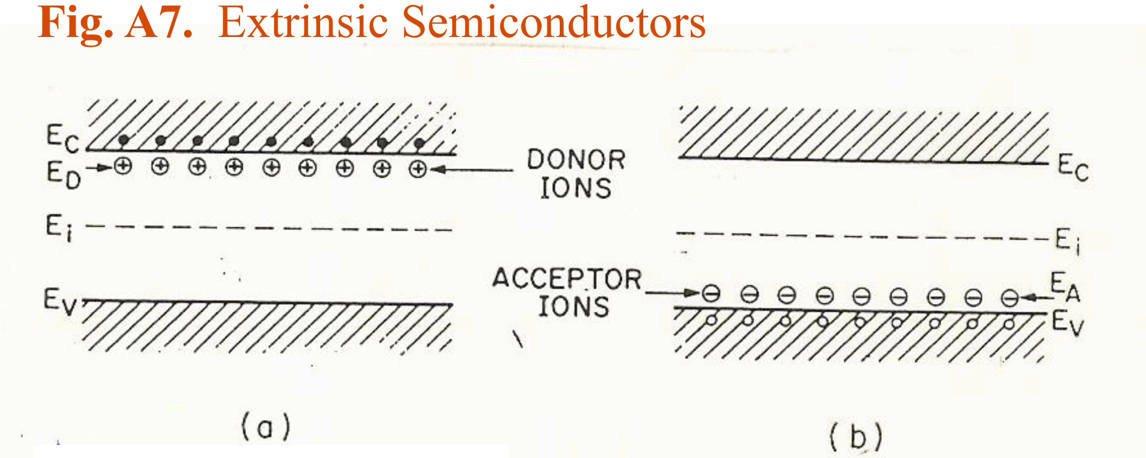
Band diagram | Density of States | Fermi distribution function | Carrier concentration

Fig. A6. n-type Semiconductors



$$F(E) = \frac{1}{1+e^{(E-E_F)/kT}} \Longrightarrow \begin{cases} F(E) \approx e^{-(E-E_F)/kT} & E - E_F \geq 3kT \\ F(E) \approx 1 - e^{-(E_F-E)/kT} & E - E_F \leq 3kT \end{cases}$$

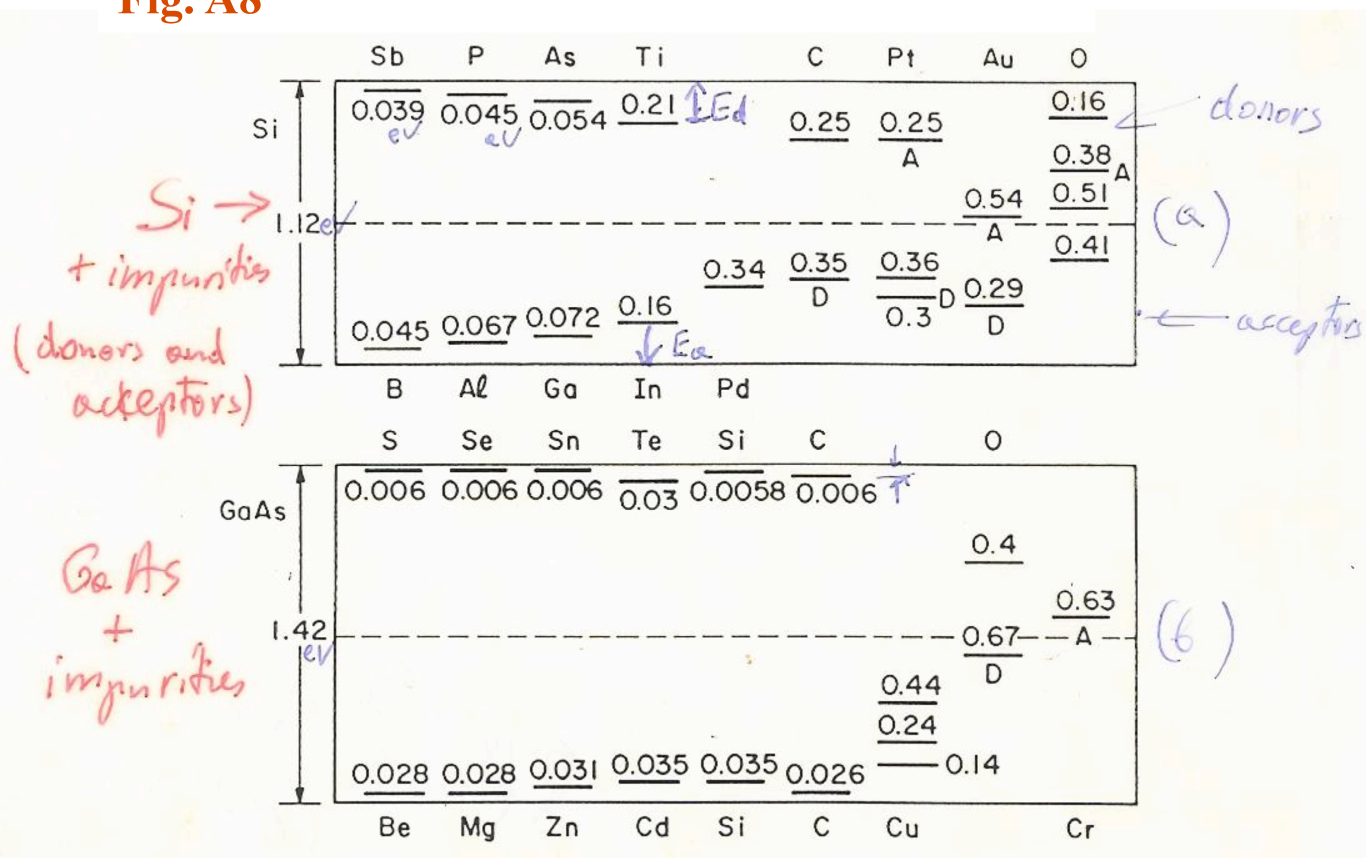
Fig. A7. Extrinsic Semiconductors



With donor ions

With acceptor ions

Fig. A8



Ionization energies in Si (a) and GaAs (b) for different impurities

<u>Diodes (p – n junction)</u>

Fig. A9. I – V characteristics of p – n silicon junction

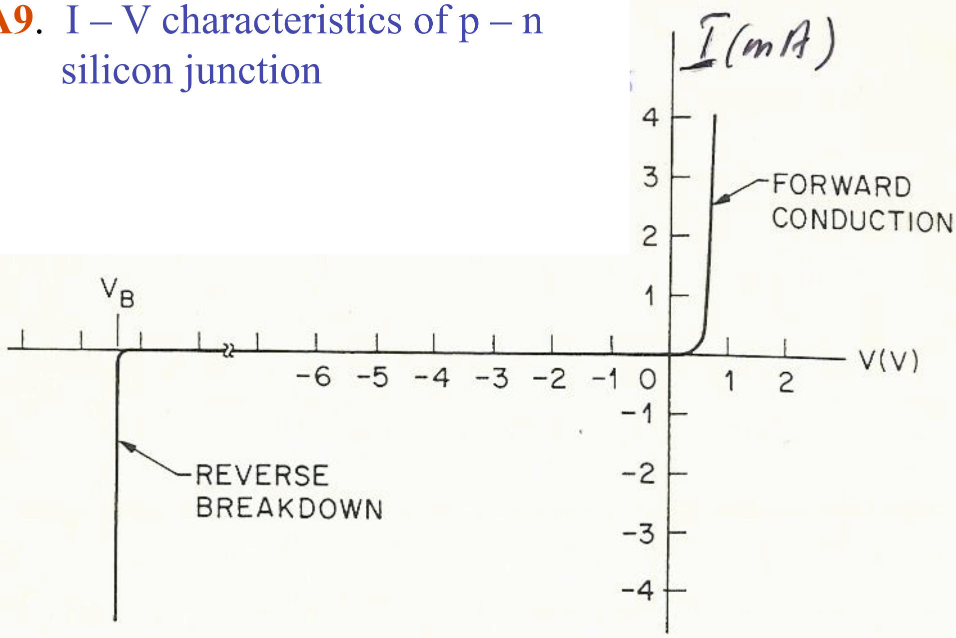
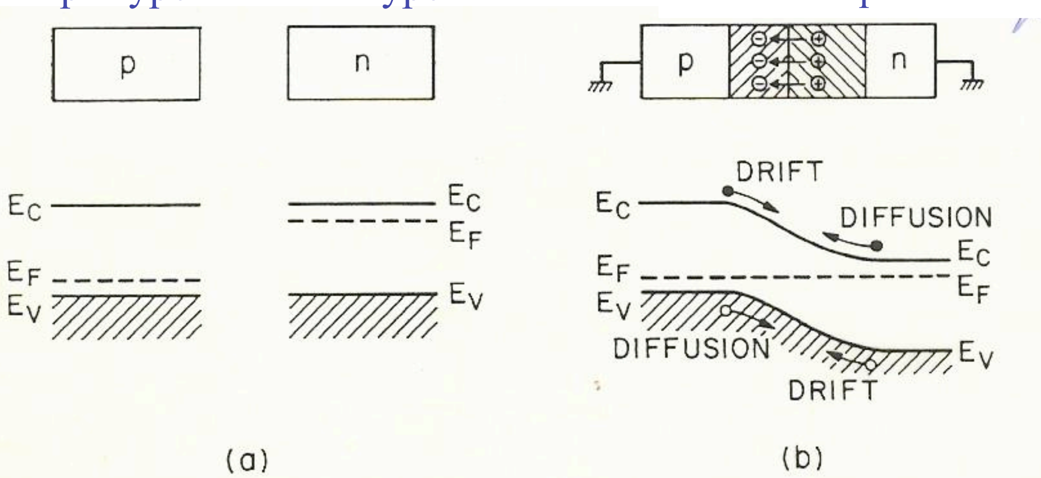


Fig. A10. Doped semiconductors and p – n junction

p - type

n - type

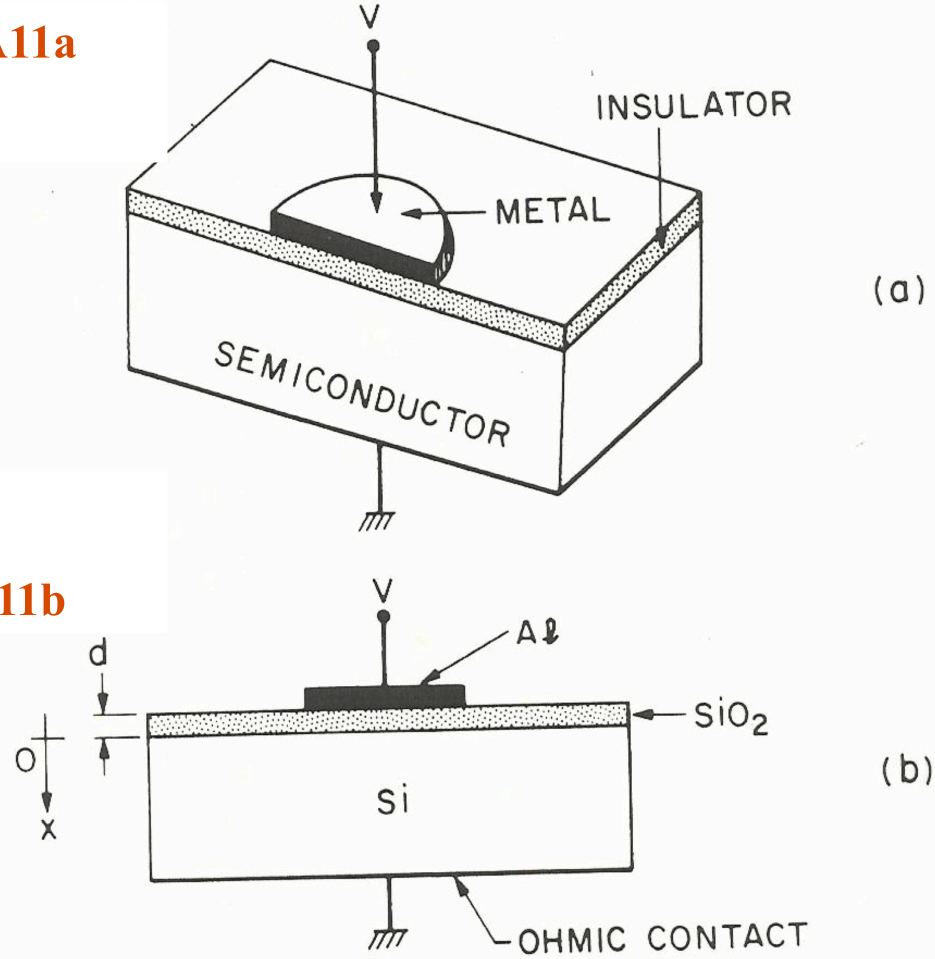
Electric field in p – n in equilibrium



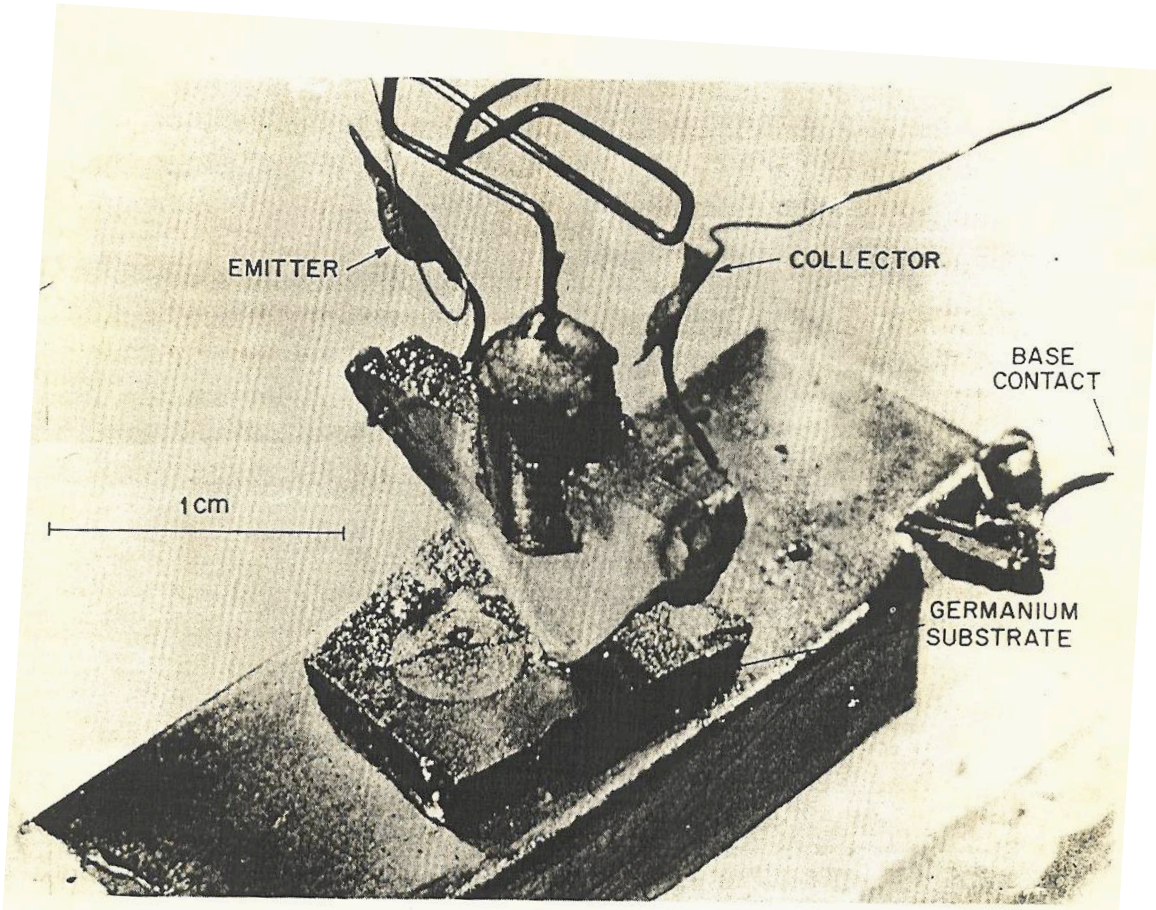
The MOS Diode

Fig. A11a

Fig. A11b



(*a*) Perspective view of an MOS diode. (*b*) Cross section of an MOS diode



The first transistor.[1]