Electronic Devices and Circuits (Formula Notes)

Thermal Voltage: V_T (Voltage Equivalent of Temperature)

$$V_T = \frac{T}{11600} \text{ volt}$$

Leakage Current (I_o)

- Also called minority carrier current or thermally generated current.
- In silicon it is in nano ampere range and in germanium it is in micro ampere range.
- I_o doubles for every 10ºC. For 1ºC, I_o increases by 7%.
- I_o is proportional to the area of the device.
- **Advantages of smaller I_o:**

(i) Suitable for high temperature applications
(*ii*) Good Thermal stability
(*iii*) No false triggering

Energy Gap: Difference between the lower energy level of conduction band (CB) E_C and upper energy level of valance band (VB) E_v is called as energy gap.

Metals: VB and CB are overlap to each other.

- This overlapping increases with temperature.
- e^- is both in CB and VB.

Insulators: Conduction band is always empty. Hence no current passes. Band gap: 5 eV – 15 eV.

Semiconductor: Energy gap is small and it is in range of 1 eV.

- At room temperature current can pass through a semi conductor.

Energy Gap	Ge	Si	Ga As
$Eg_{T=0}$	7.85 eV	1.21 eV	X X
$Eg_{T=300\,K}$	0.72 eV	1.1 eV	1.47 eV

Energy gap at temperature T

For Ge $\quad Eg_{(T)} = 0.785 - 7.2 \times 10^{-4}\, T$

For Si $\quad Eg_{(T)} = 1.21 - 3.6 \times 10^{-4}\, T$

Energy gap decreases with temperature.

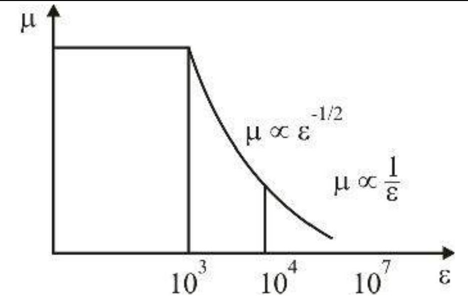
Temperature Dependence of the energy bandgap (E_g):

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta}$$

Electric Field Intensity $\quad £ = \frac{-dv}{dx} \frac{volt}{meter}$

Mobility of charge carriers $\quad \mu = \frac{\text{drift velocity}}{\text{electric field intensity}} = \frac{v}{\varepsilon} \quad \frac{m^2}{sec}$

Mobility V_s £ curve



$\varepsilon < 10^3$

$\mu = \text{constant}$

$10^3 < \varepsilon < 10^4 \quad « \propto £^{-1/2}$

$\varepsilon > 10^4 \quad « \propto \frac{1}{£}$

So drift velocity: $V_d \propto £$ $\quad V_d \propto £^{1/2}$ $\quad V_d = \text{constant}$

- Mobility indicates how quick is the e^- or hole moving from one place to another.
- Electron mobility > hole mobility
- Mobility of charge carriers decreases with the temperature.

$$\boxed{« \propto T^{-m}}$$

Mass Action Law: In a semi conductor under thermal equilibrium (at constant temperature) the product of electrons and holes in a semiconductor is always constant and equal to the square of intrinsic concentration.

$$[n_o p_o = n_i^2]$$

$n_o \rightarrow$ Concentration of e^- in conduction band

$P_o \rightarrow$ Concentration of holes in valance band

$n_i \rightarrow$ Intrinsic concentration at given temperature

$$\text{Majority carrier concentration} = \frac{n_i^2}{\text{Minority carrier concentration}}$$

Intrinsic concentration $\quad \boxed{n_i^2 = A_o T^3 e^{-\frac{Eg}{2KT}}}$

n_i is a function of temperature and energy gap.

Einstein's Equation: Relation between diffusion constant, mobility and thermal voltage.

$$\boxed{\frac{D_n}{«_n} = \frac{D_P}{«_P} = V_T = KT}$$

The unit of $\frac{D}{\mu}$ is volts. Where, $D_n \rightarrow e^-$ diffusion constant

$D_p \rightarrow$ Hole diffusion constant

Diffusion and Drift Current:

Diffusion Current: It is defined as migration of charge carriers from higher concentration to lower concentration due to concentration gradient.

Drift Current: It is flow of current through the material or device under the influence of voltage or electric field intensity.

Total current density in a semi conductor

J	=	J_n	+	J_p
↓		↓		↓
(Total current)		(Current carried by e^-)		(Current carried by holes)
J_n	=	J_n'	+	J_n''
↓		↓		↓
current due to e^-		e^- drift current density		e^- diffusion current density

For e^- $\quad \boxed{J_n = nq«_n£ + qD_n \frac{dn}{dx} A/cm^2}$

For holes $\quad \boxed{J_p = pq«_p£ - qD_p \frac{dp}{dx} A/cm^2}$

e^- diffusion length $\quad \boxed{L_n = \sqrt{D_n^2}\ cm}$

Hole diffusion length $\quad \boxed{L_P = \sqrt{D_P^2}\ cm}$

Conductivity

In Metals: Metals are uni-polar, so current is carried only by e^-

$$\pm = nq«_n$$

In metal, conductivity decreases with temperature.

In Semi Conductors $\boxed{\pm = nq«_n + pq«_P}$

$n \rightarrow$ Concentration of e^- in CB

$e \rightarrow$ Concentration of holes in VB

$\mu_n, \mu_p \rightarrow$ Mobility of holes and electrons

- Conductivity of pure semi-conductor increases with temperature

In Extrinsic Semi-conductor

For *n* type $\boxed{\pm = N_D\, q«_n}$ N_D = donor concentration

For *p* type $\boxed{\pm = N_A\, q«_p}$ N_A = acceptor concentration

In extrinsic semiconductor (SC) below the room temperature, conductivity increases. But above the room temperature their conductivity decreases.

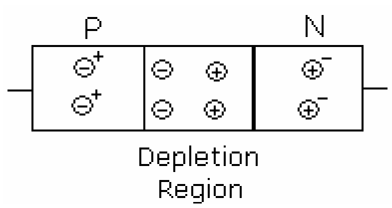
Periodic Table:

III	IV	V
B	C	N
Al	Si	P
Ga	Ge	As
In	Sn	Sb

- $e = 1.602 \times 10^{-19} C,\ m = 9.1 \times 10^{-31} kg$, 'F' force on electron in uniform electric field 'E'
- F=eE; acceleration $a = \frac{eE}{m}$
- If electron with velocity $'v'$ moves in field $'E'$ making an angle $'\theta'$ can be resolved to $v\sin\theta, v\cos\theta$.
- Effect of Magnetic Field 'B' on Electron.
- When B & Q are perpendicular path is circular $r = \frac{mv}{Be};\ Period\ 't' = \frac{2\pi m}{Be}$
- When slant with $'\theta'$ path is # Helical.
- EQUATIONS OF CRT
- ELECTROSTATIC DEFLECTION SENSITIVITY $S_e = \frac{lL}{2dV_a}$
- MAGNETIC DEFLECTION SENSITIVITY $S_m = lL\sqrt{\frac{e}{2mV_a}}$
- Velocity due to voltage V, $v = \sqrt{\frac{2eV}{m}}$

- When E and B are perpendicular and initial velocity of electron is zero, the path is Cycloidal in plane perpendicular to B & E. Diameter of Cycloid=2Q, where $Q=\frac{u}{\omega}$, $u=\frac{E}{B}$, $\omega=\frac{Be}{m}$.

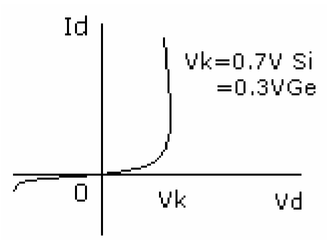
- S_i, G_e have 4 electrons in covalent bands. Valency of 4. Doping with trivalent elements makes 'p', Pentavalent elements makes 'n' semiconductor.
- Conductivity $\sigma = e\left(n\mu_n + p\mu_p\right)$ where n, p are concentrations of Dopants. μ_n & μ_p are mobility's of electron and hole respectively.



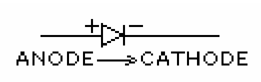
Diode equation

$$I_d = I_s\left(e^{V_d/nV_T} - 1\right)$$

$V_T = \frac{kT}{q}$; K= Boltzman Constant

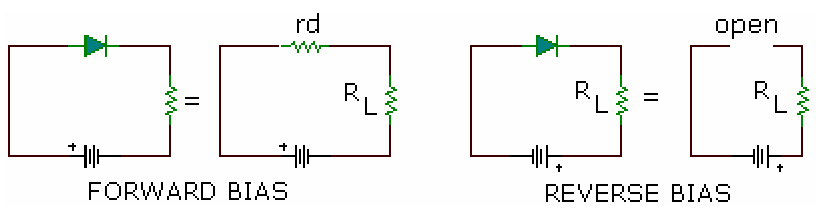


- $r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{V_T}{I}; V_o = \frac{kT}{q}\ln\left(\frac{N_A N_P}{n_i^2}\right)$



- $T = 0^0C + 273;\ q = 1.602\times10^{-19}C$

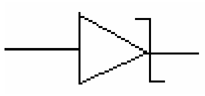
- Diode drop changes $@\,2.2mv/^0C$, Leakage current I_s doubles on 10^0C



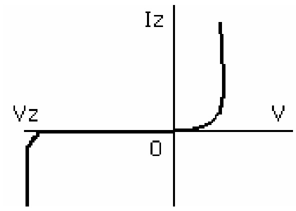
- Diffusion capacitance is $c_d = \frac{dq}{dv}$ of forward biased diode it is $\propto I$

- Transition capacitance C_T is capacitance of reverse biased diode $\propto V^{-n}$ $n = 1/2\ to\ 1/3$

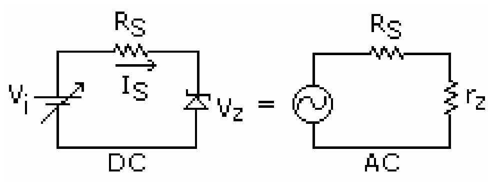
- ZENER DIODE



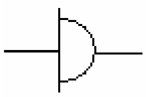
FWD Bias Normal
s_i Diode 0.7 V Drop
Reverse Bias
$Zener\ drop = V_z\ for\ V > V_z$

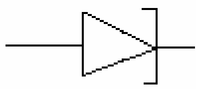


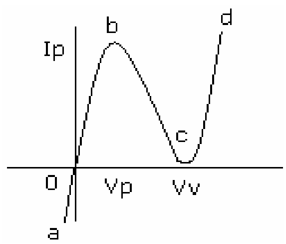
- ZENER REGULATOR
- $I_s = \frac{V_i - V_z}{R_s}; V_i >> V_z$
- $r_z = \Delta V_z / \Delta I_z$

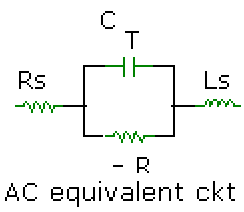


- TUNNEL DIODE



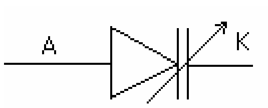


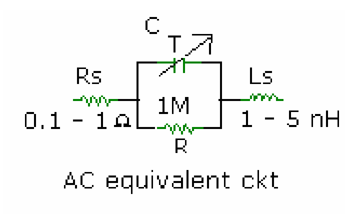


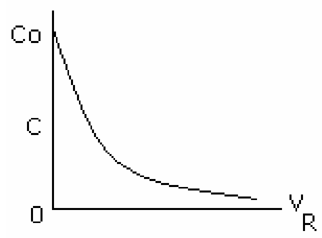


- Conducts in f/b, r/b, Quantum mechanical tunneling in region a-0-b-c.
- -ve resistance b-c, normal diode c-d.
  I_p = peak current, I_v = valley current; v_p =peak voltage ≈ 65 mV, v_v =valley voltage 0.35 V. Heavy Doping, Narrow Junction , Used for switching & HF oscillators.

- VARACTOR DIODE



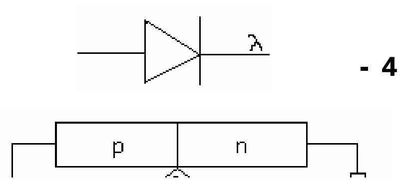


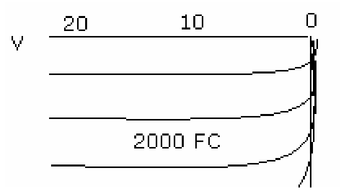


Used in reverse bias & as tuning variable capacitance.

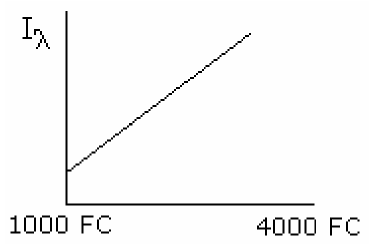
- $C_T = \frac{K}{(V_T + V_R)^n}$; n=0.3 for diffusion, n=0.5 for alloy junction, $C_T = \frac{C_o}{\left(1 + V_R / V_T\right)^n}$
- $\frac{C_B}{C_{25}}$ is figure of merit, Self resonance $f_o = \frac{1}{2\pi\sqrt{L_S C_T}}$

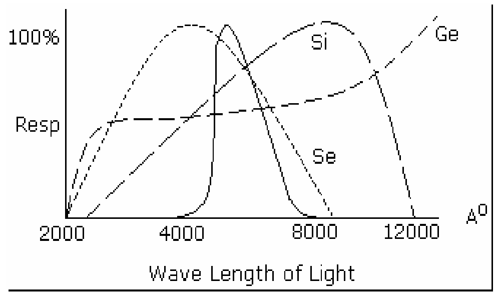
- PHOTO DIODES



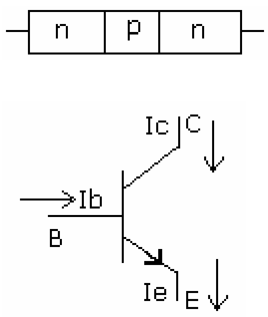


- Diode used in reverse bias for light detection.
- Different materials have individual peak response to a range of wave lengths.





- BJT, Bipolar Junction Transistor has 2 Junctions: BE, BC
- Components of current are I_{nE}, I_{pE} at EB junction where $\gamma = \dfrac{I_{nE}}{I_{nE} + I_{pE}} = \dfrac{I_{nE}}{I_E}$
- $\gamma =$ Emitter efficiency, $\beta^* = \dfrac{I_{nc}}{I_{nE}}$ transportation factor.
- $BE = f/b; BC = r/b$



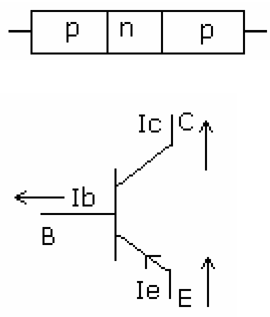
$I_e = I_b + I_c$

$\alpha = \dfrac{I_c}{I_e}; \beta = \dfrac{I_c}{I_b}$

Doping Emitter Highest

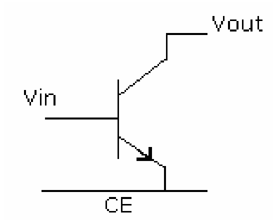
Base Lowest

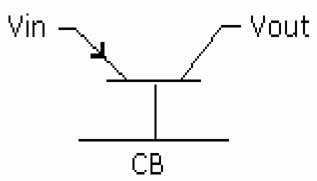
$I_e > I_c > I_b$

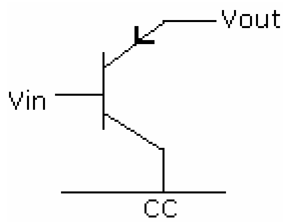


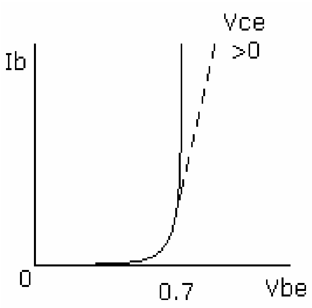
- Leakage currents : $I_{CBO}, I_{CEO}, I_{EBO}$
- $I_{CEO} = (1+\beta) I_{CBO}$

- 3 Configurations are used on BJT, CE, CB & CC

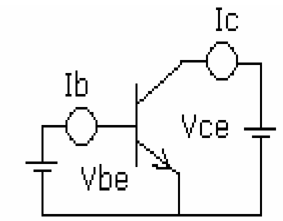


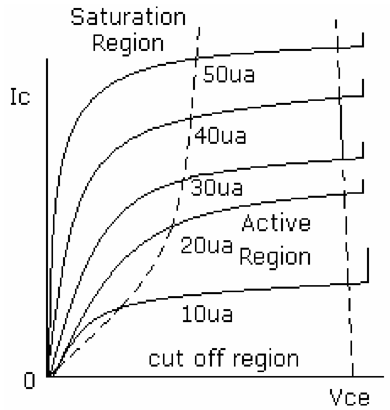






$$\beta = \frac{I_C}{I_B}\Big|_{V_{CE}}$$

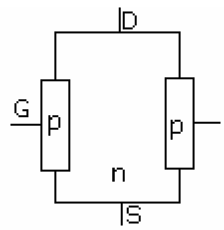




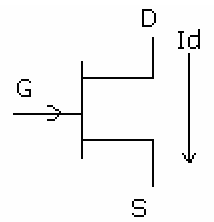
COMPARISON		
	BE	BC
SATURATION	f/b	f/b
ACTIVE	f/b	r/b
CUT OFF	r/b	r/b

AMPLIFIER COMPARISON			
	CB	CE	CF
R_i	LOW	MED	HIGH
A_I	A_I	β	$\beta+1$
A_V	High	High	<1
R_o	High	High	low

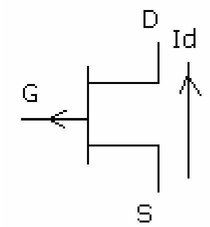
- FIELD EFFECT TRANSISTOR, FET is Unipolar Device



Construction



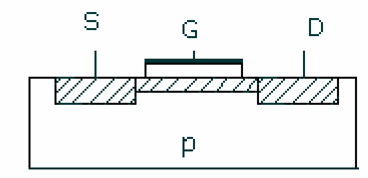
n-Channel



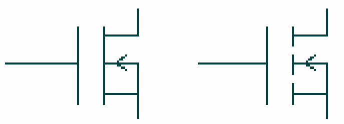
p-Channel

- S=Source, G=Gate, D=Drain
- GS Junction in Reverse Bias Always
- V_{gs} Controls Gate Width

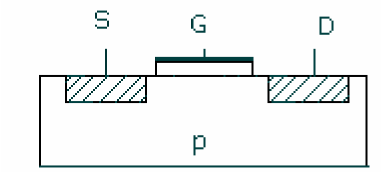
- MOSFET: Metal Oxide Semiconductor FET, IGFET



Depletion Type Mosfet

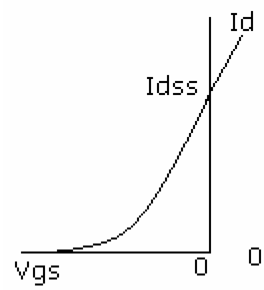


Symbols

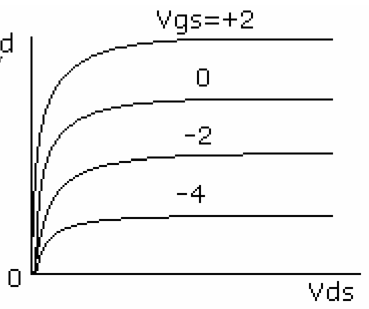


Enhancement Mosfet

- Depletion Type MOSFET can work width $V_{gs} > 0$ and $V_{gs} < 0$



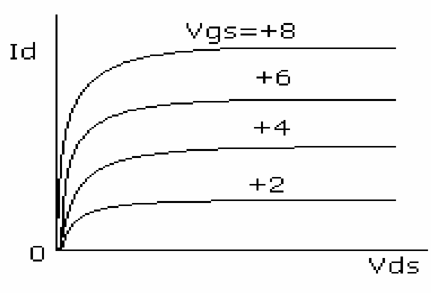
Transfer Characteristics



Forward Characteristics

MOSFET	JPET
High $R_i = 10^{10}$	-10^{8}
$R_0 = 50\ k\Omega$	$\geq 1m\Omega$
Depletion Enhancement Mode	Depletion Mode
Delicate	Rugged

- Enhancement MOSFET operates with, $V_{gs} > V_t$, $V_t = Threshold\ Voltage$



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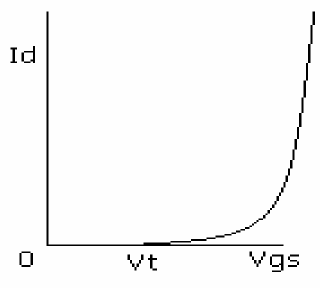
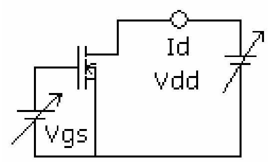


Transfer Characteristics



Circuit

$$V_{DS}(sat) = V_{GS} - V_T, \quad I_{ds}(ON) = K\left(V_{GS} - V_T\right)^2$$

JFET I_D Table

V_{gs}	I_D
0	I_{DSS}
0.3 V_P	$I_{DSS}/2$
0.5 V_P	$I_{DSS}/4$
V_P	0

COMPARISIONS

BJT	FET
Current controlled	Voltage controlled
High gain	Med gain
Bipolar	Unipolar
Temp sensitive	Little effect of T
High GBWP	Low GBWP