

CHAPTER 1:

1-

(a)

The doping density in the *p*-type material is

$$N_A = 8 \times 10^{15} \text{ atoms / cm}^3$$

The doping density in the *n*-type material is

$$N_D = 10^{17} \text{ atoms / cm}^3$$

The built in potential in a plane-abrupt *p-n* junction is

$$\psi_0 = V_T \ln \frac{N_A N_D}{n_i^2} \dots\dots\dots (1)$$

Where $V_T = \frac{K_T}{q}$

$$V_T = 26 \text{ mV at } 300^\circ\text{K}$$

n_i is the intrinsic carrier concentration in pure semiconductor

$$n_i = 1.5 \times 10^{10} \text{ cm}^{-3} \text{ at } 300^\circ\text{K}$$

By substituting all values in equation (1) we can write

$$\psi_0 = V_T \ln \frac{N_A N_D}{n_i^2}$$

$$\psi_0 = (26 \times 10^{-3}) \ln \left[\frac{(8 \times 10^{15})(10^{17})}{(1.5 \times 10^{10})^2} \right]$$

$$\psi_0 = (26 \times 10^{-3})(28.8995)$$

$$\psi_0 = 0.751387$$

$$\psi_0 = 751\text{mV}$$

The depletion layer depth in the p -type region is

$$W_1 = \left[\frac{2\varepsilon(\psi_0 + V_R)}{qN_A \left(1 + \frac{N_A}{N_D} \right)} \right]^{\frac{1}{2}} \dots\dots\dots (2)$$

q is the electron charge 1.6×10^{-19} coulomb

ε is the permittivity of the silicon 1.04×10^{-12} farad / cm

$(\psi_0 + V_R)$ is the total voltage across the junction

$$\psi_0 + V_R = 751 \times 10^{-3} + 5$$

$$\psi_0 + V_R = 5.751\text{V}$$

Substitute all these values in equation (2)

$$W_1 = \left[\frac{2(1.04 \times 10^{-12})(5.751)}{(1.6 \times 10^{-19})(8 \times 10^{15}) \left(1 + \frac{8 \times 10^{15}}{10^{17}} \right)} \right]^{\frac{1}{2}}$$

$$W_1 = \left[\frac{1.196208 \times 10^{-11}}{1.3824 \times 10^{-3}} \right]^{\frac{1}{2}}$$

$$W_1 = \left[8.653125 \times 10^{-9} \right]^{\frac{1}{2}}$$

$$W_1 = 9.3022 \times 10^{-5}$$

$W_1 = 0.93 \mu\text{m}$

The depletion layer depth in the *n*-type region is

$$W_2 = \left[\frac{2\varepsilon(\psi_0 + V_R)}{qN_D \left(1 + \frac{N_D}{N_A} \right)} \right]^{\frac{1}{2}}$$

$$W_2 = \left[\frac{2(1.04 \times 10^{-12})(5.751)}{(1.6 \times 10^{-19})(10^{17}) \left(1 + \frac{10^{17}}{8 \times 10^{15}} \right)} \right]^{\frac{1}{2}}$$

$$W_2 = \left[\frac{1.158768 \times 10^{-11}}{0.216} \right]^{\frac{1}{2}}$$

$$W_2 = \left[5.364666667 \times 10^{-11} \right]^{\frac{1}{2}}$$

$$W_2 = 7.324 \times 10^{-6}$$

$$\boxed{W_2 = 7.3 \mu\text{m}}$$

The maximum field that occurs is

$$\mathcal{E}_{\text{max}} = - \frac{q N_A W_1}{\epsilon}$$

$$\mathcal{E}_{\text{max}} = - \frac{(1.6 \times 10^{-19})(8 \times 10^{15})(0.93 \times 10^{-4})}{1.04 \times 10^{-12}}$$

$$\mathcal{E}_{\text{max}} = -114461.5385$$

$$\boxed{\mathcal{E}_{\text{max}} = -11.44 \times 10^4 \text{ V/cm}}$$

(b)

For zero external bias voltage

$$\psi_0 + V_R = 5.751$$

$$\psi_0 + 5 = 5.751$$

$$\psi_0 = 5.751 - 5$$

$$\psi_0 = 0.751$$

Now the depletion layer depth in the p -type region is

$$W_{1(\text{zero bias})} = W_1 \left(\sqrt{\frac{\psi_0}{\psi_0 + V_R}} \right)$$

$$W_{1(\text{zero bias})} = (0.93 \times 10^{-6}) \left(\sqrt{\frac{0.751}{0.751 + 5}} \right)$$

$$W_{1(\text{zero bias})} = 0.336 \times 10^{-6}$$

$W_{1(\text{zero bias})} = 0.336 \mu\text{m}$

Now the depletion layer depth in the n -type region is

$$W_{2(\text{zero bias})} = W_2 \left(\sqrt{\frac{\psi_0}{\psi_0 + V_R}} \right)$$

$$W_{2(\text{zero bias})} = (7.3 \times 10^{-6}) \left(\sqrt{\frac{0.751}{0.751 + 5}} \right)$$

$W_{2(\text{zero bias})} = 2.64 \mu\text{m}$

For zero external bias voltage maximum field occurs

$$\xi_{\text{max}(\text{zero bias})} = \xi_{\text{max}} \times \frac{W_{1(\text{zero bias})}}{W_1}$$

$$\xi_{\text{max}(\text{zero bias})} = -11.44 \times 10^4 \times \frac{0.336 \times 10^{-6}}{0.93 \times 10^{-6}}$$

$$\xi_{\text{max}(\text{zero bias})} = -41331.6129$$

$$\boxed{\mathcal{E}_{\text{max(zero bias)}} = -4.133 \times 10^4 \text{ V/cm}}$$

Given forward bias voltage = 0.3V
Built-in potential for this forward voltage

$$\psi_0 - 0.3 = 0.751 - 0.3$$

$$\psi_0 - 0.3 = 0.451 \text{ V}$$

Now the depletion layer depth in the *p*-type region is

$$W_{1(0.3\text{V forward})} = W_1 \left(\sqrt{\frac{0.451}{5.751}} \right)$$

$$W_{1(0.3\text{V forward})} = (0.93 \times 10^{-6}) \left(\sqrt{\frac{0.451}{5.751}} \right)$$

$$W_{1(0.3\text{V forward})} = 0.2604 \times 10^{-6}$$

$$\boxed{W_{1(0.3\text{V forward})} = 0.26 \mu\text{m}}$$

The depletion layer depth in the *n*-type region is

$$W_{2(0.3\text{V forward})} = W_2 \left(\sqrt{\frac{0.451}{5.751}} \right)$$

$$W_{2(0.3\text{V forward})} = (7.3 \times 10^{-6}) \left(\sqrt{\frac{0.451}{5.751}} \right)$$

$$W_{2(0.3\text{V forward})} = 2.044 \times 10^{-6}$$

$$\boxed{W_{2(0.3\text{V forward})} = 2.044 \mu\text{m}}$$

The maximum field that occurs in 0.3V forward bias

$$\mathcal{E}_{\text{max}(0.3\text{V forward})} = \mathcal{E}_{\text{max}} \times \frac{W_{1(0.3\text{V forward})}}{W_1}$$

$$\mathcal{E}_{\text{max}(0.3\text{V forward})} = -11.44 \times 10^4 \times \frac{0.26 \times 10^{-6}}{0.93 \times 10^{-6}}$$

$$\mathcal{E}_{\text{max}(0.3\text{V forward})} = -31982.7957$$

$$\boxed{\mathcal{E}_{\text{max}(0.3\text{V forward})} = -3.198 \times 10^4 \text{ V/cm}}$$

2-

The zero bias junction capacitance is

$$C_{j(\text{zero})} = A \left[\frac{q \epsilon N_A N_D}{2 (N_A + N_D)} \right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0}} \dots\dots\dots (1)$$

Given parameters

$$q = 1.6 \times 10^{-19} \text{ coulomb}$$

$$\epsilon = 1.04 \times 10^{-12} \text{ farad/cm}$$

$$\text{The doping density in the } p\text{-type material is } N_A = 8 \times 10^{15} \text{ atoms / cm}^3$$

$$\text{The doping density in the } n\text{-type material is } N_D = 10^{17} \text{ atoms / cm}^3$$

$$\text{The built in potential of the depletion layer is } \psi_0 = 0.751 \text{ V}$$

$$\text{The junction area } A = 2 \times 10^{-5} \text{ cm}^2$$

Now equation (1) becomes

$$C_{j(\text{zero})} = 2 \times 10^{-5} \left[\frac{1.6 \times 10^{-19} \times 1.04 \times 10^{-12} \times 8 \times 10^{15} \times 10^{17}}{2 (8 \times 10^{15} + 10^{17})} \right]$$

$$C_{j(\text{zero})} = 2 \times 10^{-5} \left[\frac{133.12}{2.16 \times 10^{17}} \right]^{\frac{1}{2}} \times \frac{1}{\sqrt{0.751}}$$

$$C_{j(\text{zero})} = 5.72934 \times 10^{-13} \text{ F}$$

$$C_{j(\text{zero})} = 5.72934 \times 10^{-13} \text{ F}$$

$C_{j(\text{zero})} = 0.57 \text{ pF}$

Given reverse bias voltage $V_R = 5V$
Reverse bias junction capacitance is

$$C_{j(\text{reverse})} = A \left[\frac{q \epsilon N_A N_D}{2(N_A + N_D)} \right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0 + V_R}} \dots\dots\dots (2)$$

$$\frac{(2)}{(1)} \Rightarrow \frac{C_{j(\text{reverse})}}{C_{j(\text{zero})}} = \frac{A \left[\frac{q \epsilon N_A N_D}{2(N_A + N_D)} \right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0 + V_R}}}{A \left[\frac{q \epsilon N_A N_D}{2(N_A + N_D)} \right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0}}}$$

$$\frac{C_{j(\text{reverse})}}{C_{j(\text{zero})}} = \frac{\frac{1}{\sqrt{\psi_0 + V_R}}}{\frac{1}{\sqrt{\psi_0}}}$$

$$\frac{C_{j(\text{reverse})}}{C_{j(\text{zero})}} = \frac{1}{\sqrt{1 + \frac{V_R}{\psi_0}}}$$

$$C_{j(\text{reverse})} = \frac{C_{j(\text{zero})}}{\sqrt{1 + \frac{V_R}{\psi_0}}}$$

$$C_{j(\text{reverse})} = \frac{0.57 \times 10^{-12}}{\sqrt{1 + \frac{5}{0.751}}}$$

$$C_{j(\text{reverse})} = 2.05979 \times 10^{-13} \text{ F}$$

$C_{j(\text{reverse})} = 0.2 \text{ pF}$

Given forward bias voltage $V_f = 0.3 \text{ V}$

Forward bias junction capacitance is

$$C_{j(\text{forward})} = A \left[\frac{q \epsilon N_A N_D}{2(N_A + N_D)} \right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0 - V_f}} \dots\dots\dots (3)$$

$$\frac{(3)}{(1)} \Rightarrow \frac{C_{j(\text{forward})}}{C_{j(\text{zero})}} = \frac{A \left[\frac{q \epsilon N_A N_D}{2(N_A + N_D)} \right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0 - V_f}}}{A \left[\frac{q \epsilon N_A N_D}{2(N_A + N_D)} \right]^{\frac{1}{2}} \frac{1}{\sqrt{\psi_0}}}$$

$$\frac{C_{j(\text{forward})}}{C_{j(\text{zero})}} = \frac{1}{\sqrt{1 - \frac{V_f}{\psi_0}}}$$

$$C_{j(\text{forward})} = \frac{C_{j(\text{zero})}}{\sqrt{1 - \frac{V_f}{\psi_0}}}$$

$$C_{j(\text{forward})} = \frac{0.57 \times 10^{-12}}{\sqrt{1 - \frac{0.3}{0.751}}}$$

$$C_{j(\text{forward})} = 7.3554 \times 10^{-13} \text{ F}$$

$C_{j(\text{forward})} = 0.74 \text{ pF}$

3-

The maximum electric field value in the depletion region is

$$|\epsilon_{\text{max}}| = \left[\frac{2qN_A N_D V_R}{\epsilon(N_A + N_D)} \right]^{\frac{1}{2}} \dots\dots\dots (1)$$

Given parameters

$$q = 1.6 \times 10^{-19} \text{ coulomb}$$

$$\epsilon = 1.04 \times 10^{-12} \text{ farad/cm}$$

$$\text{The doping density in the } p\text{-type material is } N_A = 8 \times 10^{15} \text{ atoms / cm}^3$$

$$\text{The doping density in the } n\text{-type material is } N_D = 10^{17} \text{ atoms / cm}^3$$

$$\text{The maximum electric field } |\epsilon_{\text{max}}| = \epsilon_{\text{crit}} = 4 \times 10^5 \text{ V/cm}$$

Now equation (1) becomes

$$4 \times 10^5 = \left[\frac{2 \times 1.6 \times 10^{-19} \times 8 \times 10^{15} \times 10^{17} \times V_R}{1.04 \times 10^{-12} (8 \times 10^{15} + 10^{17})} \right]^{\frac{1}{2}}$$

$$4 \times 10^5 = \left[\frac{2.56 \times 10^{14} \times V_R}{112320} \right]^{\frac{1}{2}}$$

$$16 \times 10^{10} = \frac{2.56 \times 10^{14} \times V_R}{112320}$$

$$V_R = \frac{112320 \times 16 \times 10^{10}}{2.56 \times 10^{14}}$$

$V_R = 70.2 \text{ V}$

4-

The maximum electric field value in the depletion region is

$$|\xi_{\max}| = \left[\frac{2qN_A N_D V_R}{\epsilon (N_A + N_D)} \right]^{\frac{1}{2}} \dots\dots\dots (1)$$

If junction curvature causes the maximum field at a practical junction to be 1.5 times the theoretical value, then we can write

$$|\xi_{\max}| = 1.5 \left[\frac{2qN_A N_D V_R}{\epsilon (N_A + N_D)} \right]^{\frac{1}{2}} \dots\dots\dots (2)$$

Given that one side of the junction is much more heavily doped than the other.

$$N_A \gg N_D$$

$$\xi_{\text{crit}} = 3 \times 10^5 \text{ V/cm}$$

The break down voltage $V_R = 150 \text{ V}$

From equation (2) we can write

$$3 \times 10^5 = 1.5 \left[\frac{2qN_A N_D V_R}{\epsilon (N_A + N_D)} \right]^{\frac{1}{2}}$$

Squaring on both sides we have

$$9 \times 10^{10} = 2.25 \left[\frac{2qN_A N_D V_R}{\epsilon (N_A + N_D)} \right]$$

$$V_R = \left(\frac{9 \times 10^{10}}{2.25} \right) \left[\frac{\epsilon (N_A + N_D)}{2qN_A N_D} \right]$$

Given that $N_A \gg N_D$, so we can modify above equation as below

$$V_R = \left(\frac{9 \times 10^{10}}{2.25} \right) \left[\frac{\varepsilon(N_A)}{2qN_A N_D} \right]$$
$$V_R = \left(\frac{9 \times 10^{10}}{2.25} \right) \left(\frac{\varepsilon}{2qN_D} \right)$$
$$N_D = \left(\frac{9 \times 10^{10}}{2.25} \right) \left(\frac{\varepsilon}{2qV_R} \right) \dots\dots\dots (3)$$

By substituting $\varepsilon = 1.04 \times 10^{-12}$ farad/cm , $q = 1.6 \times 10^{-19}$ columb and $V_R = 150$ V in equation (3) we can get

$$N_D = \left(\frac{9 \times 10^{10}}{2.25} \right) \left(\frac{1.04 \times 10^{-12}}{2(1.6 \times 10^{-19})(150)} \right)$$
$$N_D = (4 \times 10^{10})(21666.66667)$$
$$N_D = 8.6666 \times 10^{14} \text{ atoms/cm}^3$$

$N_D = 8.67 \times 10^{14} \text{ atoms/cm}^3$

5-

Consider *npn* transistor

The collector doping density in the transistor is $N_D = 6 \times 10^{15}$ atoms/cm³

The break down voltage

$$BV_{CBO} = \frac{\epsilon(N_A + N_D)}{2qN_A N_D} \epsilon_{crit}^2 \dots\dots\dots (1)$$

Given that collector doping density (N_D) is much lesser than the base doping density (N_A)

i.e. $N_D \ll N_A$

Now equation (1) becomes

$$BV_{CBO} = \frac{\epsilon(N_A)}{2qN_A N_D} \epsilon_{crit}^2$$
$$BV_{CBO} = \frac{\epsilon}{2qN_D} \epsilon_{crit}^2 \dots\dots\dots (2)$$

By substituting $\epsilon = 1.04 \times 10^{-12}$ farad/cm , $q = 1.6 \times 10^{-19}$ columb, $N_D = 6 \times 10^{15}$ atoms/cm³ and $\epsilon_{crit} = 3 \times 10^5$ V/cm in equation (2) we can get

$$BV_{CBO} = \left(\frac{1.04 \times 10^{-12}}{2(1.6 \times 10^{-19})(6 \times 10^{15})} \right) (3 \times 10^5)^2$$
$$BV_{CBO} = \left(\frac{1.04 \times 10^{-12}}{1.92 \times 10^{-3}} \right) (9 \times 10^{10})$$
$$BV_{CBO} = 48.75V$$

We have $BV_{CBO} = \frac{BV_{CBO}}{n\sqrt{\beta_F}} \dots\dots\dots (3)$

Given parameters:

$n = 4,$

$\beta_F = 200$

By substituting $n = 4,$ $\beta_F = 200$ and $BV_{CBO} = 48.75V$ in equation (3), we can write

$$BV_{CBO} = \frac{48.75}{4\sqrt{200}}$$
$$BV_{CBO} = \frac{48.75}{3.7606}$$
$$BV_{CBO} = 12.9633$$
$$\boxed{BV_{CBO} = 13V}$$

6-

Consider *npn* transistor

The collector doping density in the transistor is $N_D = 10^{15}$ atoms/cm³

The break down voltage

$$BV_{CBO} = \frac{\epsilon(N_A + N_D)}{2qN_A N_D} \xi_{crit}^2 \dots\dots\dots (1)$$

Given that collector doping density (N_D) is much lesser than the base doping density (N_A)

$$i.e. N_D \ll N_A$$

Now equation (1) becomes

$$BV_{CBO} = \frac{\epsilon(N_A)}{2qN_A N_D} \xi_{crit}^2$$
$$BV_{CBO} = \frac{\epsilon}{2qN_D} \xi_{crit}^2 \dots\dots\dots (2)$$

By substituting $\epsilon = 1.04 \times 10^{-12}$ farad/cm , $q = 1.6 \times 10^{-19}$ columb , $N_D = 10^{15}$ atoms/cm³ and $\xi_{crit} = 3 \times 10^5$ V/cm in equation (2) we can get

$$BV_{CBO} = \left(\frac{1.04 \times 10^{-12}}{2(1.6 \times 10^{-19})(10^{15})} \right) (3 \times 10^5)^2$$
$$BV_{CBO} = \left(\frac{1.04 \times 10^{-12}}{3.2 \times 10^{-4}} \right) (9 \times 10^{10})$$
$$BV_{CBO} = 292.5V$$

We have $BV_{CBO} = \frac{BV_{CBO}}{n\sqrt{\beta_F}} \dots\dots\dots (3)$

Given parameters:

$$n = 4,$$

$$\beta_F = 400$$

By substituting $n = 4$, $\beta_F = 400$ and $BV_{CBO} = 292.5V$ in equation (3), we can write

$$BV_{CBO} = \frac{292.5}{4\sqrt{400}}$$
$$BV_{CBO} = \frac{292.5}{4.472}$$
$$BV_{CBO} = 65.405V$$

$BV_{CBO} = 65.4V$

7-

Given parameters

$$\beta_F = 100,$$

$$V_A = 50\text{V},$$

$$BV_{CBO} = 120\text{V} \text{ and}$$

$$n = 4$$

We know that $\alpha_F = \frac{\beta_F}{\beta_F + 1}$

$$\alpha_F = \frac{100}{100 + 1}$$

$$\alpha_F = 0.99$$

Given $I_C - V_{CE}$ characteristic equation

$$I_C = \left(1 + \frac{V_{CE}}{V_A}\right) \frac{M \alpha_F}{1 - M \alpha_F} I_B \dots\dots\dots (1)$$

Here $M = \frac{1}{1 - \left(\frac{V_{CB}}{BV_{CBO}}\right)^n}$

Assume $V_{CB} = V_{CE}$, then

$$M = \frac{1}{1 - \left(\frac{V_{CE}}{120}\right)^4}$$

$$M = \frac{120^4}{120^4 - (V_{CE})^4}$$

Now equation (1) becomes

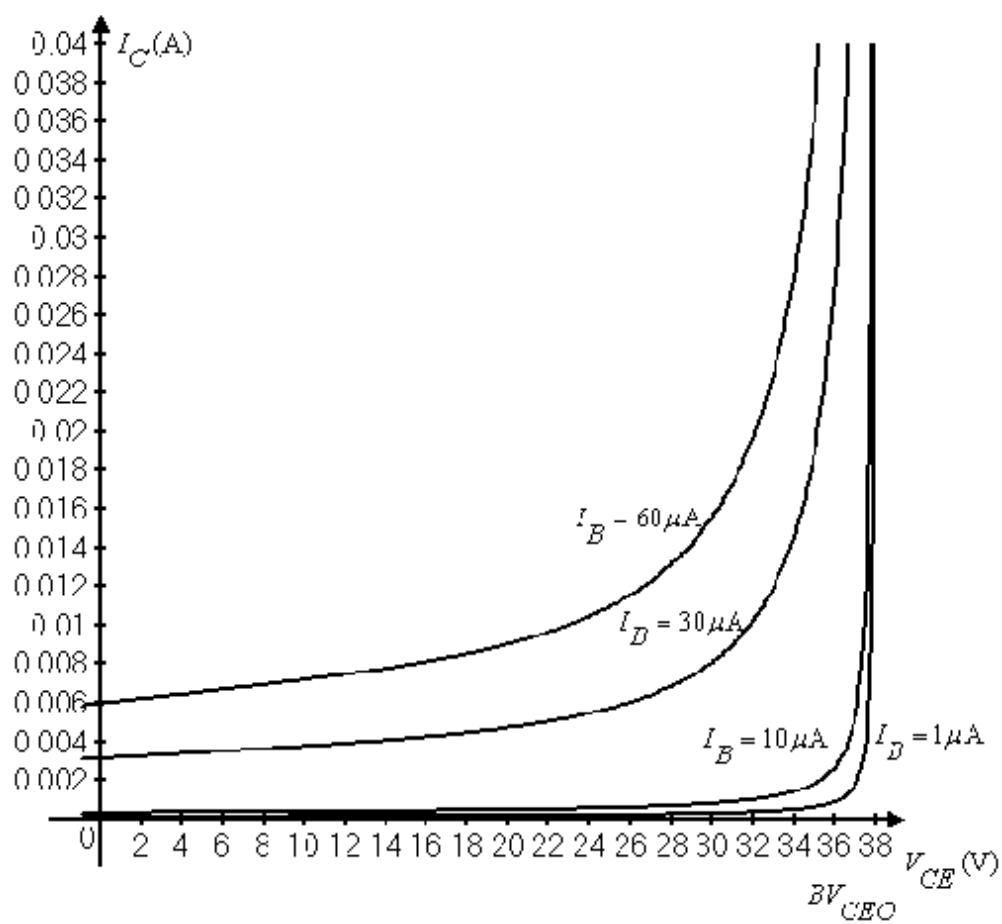
$$I_C = \left(1 + \frac{V_{CE}}{50}\right) \left[\frac{\left(\frac{120^4}{120^4 - (V_{CE})^4}\right)^{0.99}}{1 - \left(\frac{120^4}{120^4 - (V_{CE})^4}\right)^{0.99}} \right] I_B$$

$$I_C = \left(\frac{50 + V_{CE}}{50}\right) \left[\frac{120^4 \times 0.99}{120^4 - (V_{CE})^4 - 120^4 \times 0.99} \right] I_B$$

$$I_C = \left[\frac{4105728(50 + V_{CE})}{2073600 - (V_{CE})^4} \right] I_B$$

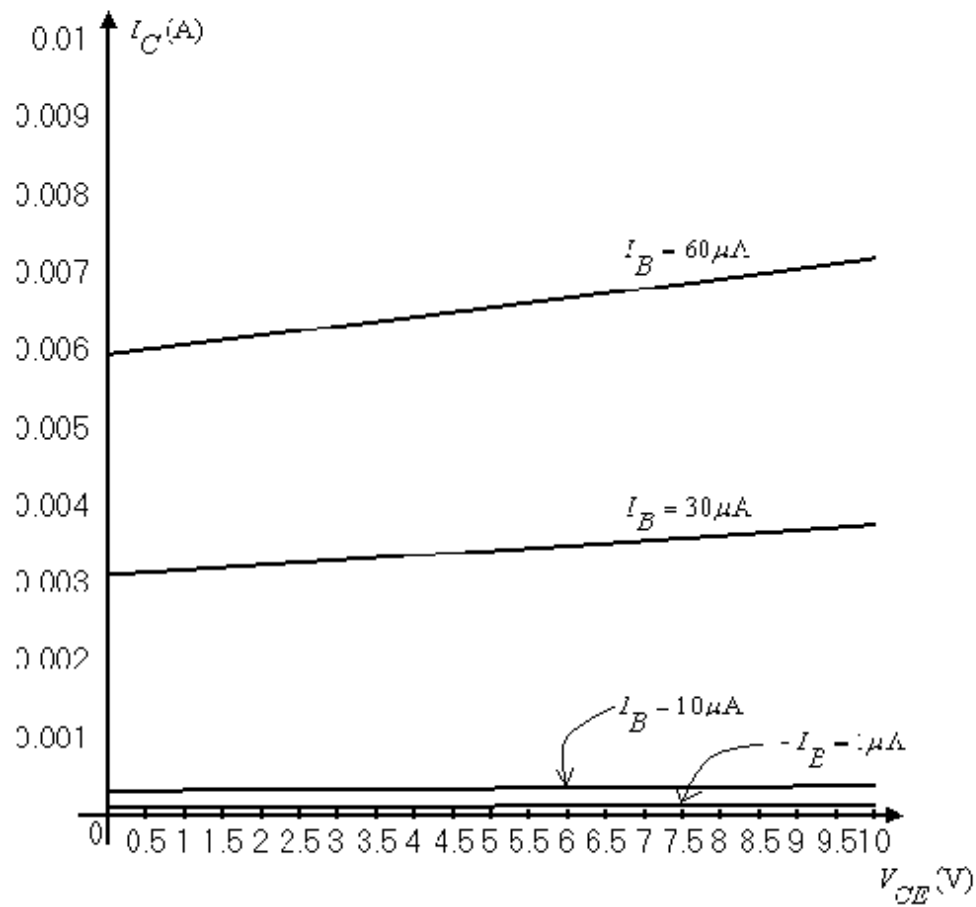
(a)

For different values of I_B we can get $I_C - V_{CE}$ characteristic curve as below



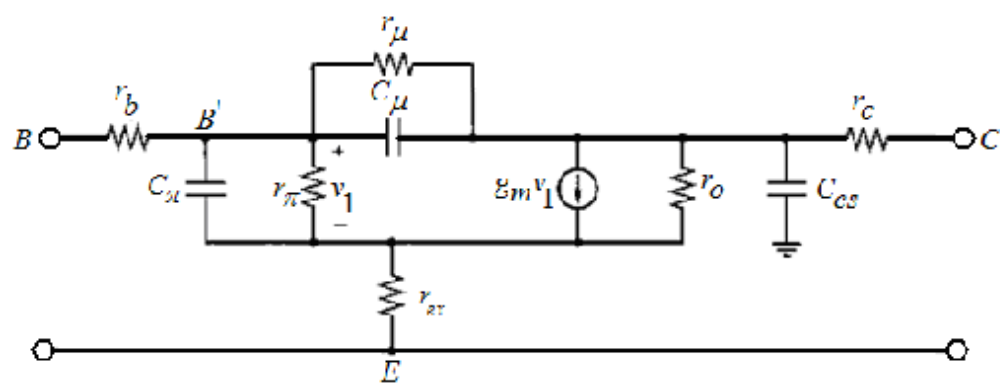
(b)

$I_C - V_{CE}$ characteristic curve for V_{CE} 0 to 10V



8-

Bipolar transistor small-signal equivalent circuit is as below



Given data
 $I_C = 0.2\text{mA}$, $V_{CB} = 3\text{V}$, $V_{CS} = 4\text{V}$
 $C_{je0} = 20\text{fF}$, $C_{\mu0} = 10\text{fF}$, $C_{cs0} = 20\text{fF}$, $\beta_0 = 100$, $\tau_F = 15\text{ps}$,
 $\eta = 10^{-3}$, $r_b = 200\Omega$, $r_c = 100\Omega$, $r_{ex} = 4\Omega$ and $r_\mu = 5\beta_0 r_o$
Here assumption is $\psi_0 = 0.55\text{V}$

The collector base capacitance is

$$C_\mu = \frac{C_{\mu0}}{\left(1 + \frac{V_{CB}}{\psi_{0C}}\right)^{n_c}} \dots\dots\dots (1)$$

n_c value varies from 0.2 to 0.5.

Let us assume $n_c = 0.5$

Now equation (1) become

$$C_\mu = \frac{C_{\mu0}}{\sqrt{1 + \frac{V_{CB}}{\psi_{0C}}}}$$

$$C_\mu = \frac{10 \times 10^{-15}}{\sqrt{1 + \frac{3}{0.55}}}$$

$$C_\mu = \frac{10 \times 10^{-15}}{\sqrt{6.454545}}$$

$$C_\mu = 3.936 \times 10^{-15}$$

$$C_\mu = 3.936\text{fF}$$

Collector substrate capacitance is

$$C_{cs} = \frac{C_{cs0}}{\left(1 + \frac{V_{cs}}{\psi_{0s}}\right)^{n_s}} \dots\dots\dots (2)$$

Here $n_s = 0.5$

Now equation (2) becomes

$$C_{cs} = \frac{C_{cs0}}{\sqrt{1 + \frac{V_{cs}}{\psi_{0s}}}}$$

$$C_{cs} = \frac{20 \times 10^{-15}}{\sqrt{1 + \frac{4}{0.55}}}$$

$$C_{cs} = \frac{20 \times 10^{-15}}{2.876}$$

$$C_{cs} = 6.95 \times 10^{-15}$$

$$C_{cs} = 6.95 \text{fF}$$

Transconductance is

$$g_m = \frac{I_C}{V_T}$$

$$g_m = \frac{0.2 \times 10^{-3}}{26 \times 10^{-3}}$$

$$g_m = 7.692 \times 10^{-3}$$

$$g_m = 7.692 \text{ mV/A}$$

Input resistance is

$$r_x = \frac{\beta_o}{g_m}$$

$$r_x = \frac{100}{7.692 \times 10^{-3}}$$

$$r_x = 13000.52 \Omega$$

$$r_x = 13 \text{ k}\Omega$$

Output resistance is

$$r_o = \frac{V_A}{I_C} = \frac{1}{\eta g_m}$$

$$r_o = \frac{1}{10^{-3} \times 7.692 \times 10^{-3}}$$

$$r_o = 130005.2 \Omega$$

$$r_o = 130 \text{ k}\Omega$$

Collector-base resistance is

$$r_\mu = 5 \beta_o r_o$$

$$r_\mu = 5(100)(130 \times 10^3)$$

$$r_\mu = 65 \text{ M}\Omega$$

Base charge capacitance is

$$C_b = \tau_F g_m$$

Given $\tau_F = 15\text{pF}$

$$C_b = (15 \times 10^{-12})(7.692 \times 10^{-3})$$

$$C_b = 115.38 \times 10^{-15}$$

$$C_b = 115.38 \text{ fF}$$

Base-emitter capacitor is

$$C_x = C_b + C_{je}$$

We know that $C_{je} \approx 2C_{je0}$

$$C_{je} = 2(20 \times 10^{-15})$$

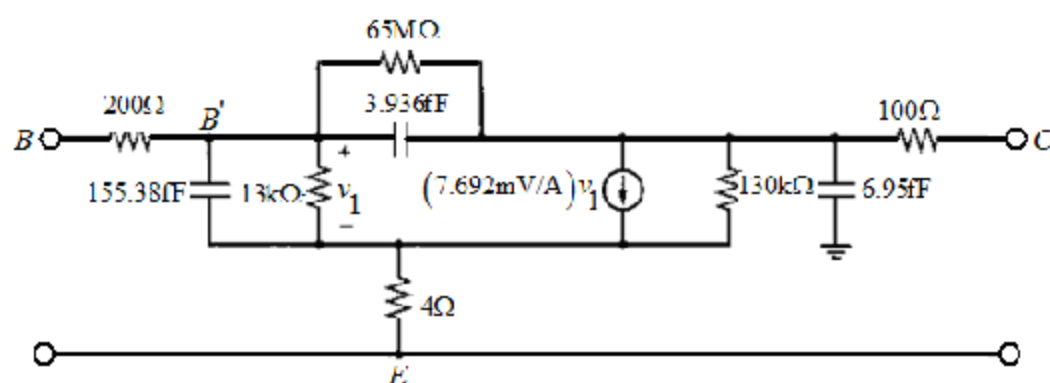
$$C_{je} = 40 \times 10^{-15}$$

$$C_x = 115.38 \times 10^{-15} + 40 \times 10^{-15}$$

$$C_x = 155.38 \times 10^{-15}$$

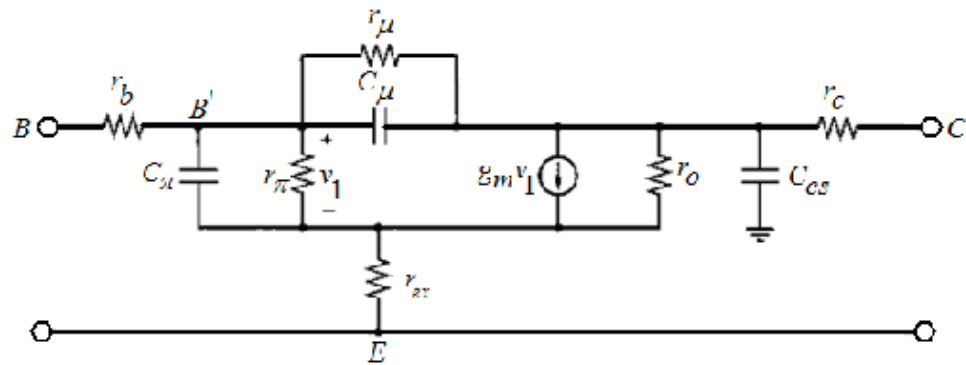
$$C_x = 155.38 \text{ fF}$$

The equivalent circuit with all parameter values is



9-

Bipolar transistor small-signal equivalent circuit is as below



Given data
 $I_C = 1\text{mA}$, $V_{CB} = 1\text{V}$, $V_{CS} = 2\text{V}$
 $C_{je0} = 20\text{fF}$, $C_{\mu0} = 10\text{fF}$, $C_{cs0} = 20\text{fF}$, $\beta_0 = 100$, $\tau_F = 15\text{ps}$,
 $\eta = 10^{-3}$, $r_b = 200\Omega$, $r_c = 100\Omega$, $r_{ex} = 4\Omega$ and $r_\mu = 5\beta_0 r_o$
Here assumption is $\psi_0 = 0.55\text{V}$

The collector base capacitance is

$$C_\mu = \frac{C_{\mu0}}{\left(1 + \frac{V_{CB}}{\psi_{0C}}\right)^{n_c}} \dots\dots\dots (1)$$

n_c value varies from 0.2 to 0.5.

Let us assume $n_c = 0.5$

Now equation (1) become

$$C_{\mu} = \frac{C_{\mu 0}}{\sqrt{1 + \frac{V_{CB}}{\psi_{0c}}}}$$

$$C_{\mu} = \frac{10 \times 10^{-15}}{\sqrt{1 + \frac{1}{0.55}}}$$

$$C_{\mu} = \frac{10 \times 10^{-15}}{\sqrt{2.81818}}$$

$$C_{\mu} = 5.96 \times 10^{-15}$$

$$C_{\mu} = 5.96 \text{fF}$$

Collector substrate capacitance is

$$C_{cs} = \frac{C_{cs0}}{\left(1 + \frac{V_{CS}}{\psi_{0s}}\right)^{n_s}} \dots\dots\dots (2)$$

Here $n_s = 0.5$

Now equation (2) becomes

$$C_{cs} = \frac{C_{cs0}}{\sqrt{1 + \frac{V_{cs}}{\psi_{0s}}}}$$

$$C_{cs} = \frac{20 \times 10^{-15}}{\sqrt{1 + \frac{2}{0.55}}}$$

$$C_{cs} = \frac{20 \times 10^{-15}}{2.1532}$$

$$C_{cs} = 9.288 \times 10^{-15}$$

$$C_{cs} = 9.288 \text{ fF}$$

Transconductance is

$$g_m = \frac{I_C}{V_T}$$

$$g_m = \frac{1 \times 10^{-3}}{26 \times 10^{-3}}$$

$$g_m = 38.462 \times 10^{-3}$$

$$g_m = 38.462 \text{ mV/A}$$

Input resistance is

$$r_x = \frac{\beta_o}{g_m}$$