FORWARD BIASED JUNCTION ADMITTANCE

The junction diode under forward bias condition \( V_A > 0 \) and a small signal is also modeled by an admittance.

\[ \begin{array}{c}
\text{C}_j \\
\hline
\text{G} \\
\hline
\text{C}_D \\
\hline
\text{R}_S \\
\hline
\end{array} \]

In addition to the majority carrier response which yields a junction capacitance, the minority carrier response yields to diffusion capacitance and to the conductance \( G \cdot R_S \) is the total resistances of both \( P \) and \( n \) bulk and their metal contact resistances.

To derive the diffusion admittance of a junction, the minority carrier response, we assume a \( P^+ - n \) junction, therefore concern ourselves only with \( n(x,t) \) and also \( p(x,t) \) in \( n \)-region.

The minority carrier continuity equation for a uniformly doped \( n \)-region is

\[ \frac{\partial \Delta n(x,t)}{\partial t} = D_p \frac{\partial^2 \Delta n(x,t)}{\partial x^2} - \frac{\Delta n(x,t)}{\tau_p} \]

And

\[ \Delta n(x,t) = \overline{\Delta n}(x) + n(x,t) \]

If we take the first and second derivative of \( \Delta n(x,t) \) and remember that \( \frac{\partial \overline{\Delta n}(x)}{\partial t} = 0 \), and also the signal part

\[ \overline{n}(x,t) = \overline{n}(x) f(t) \]

then \( f(t) = e^{j\omega t} \) and solve the equation we get

\[ n(0,t) = P_{nc} e^{\frac{qV_A}{KT}} + P_{nc} e^{\frac{qV_A}{KT}} \frac{qV_A(t)}{KT} \]

And

\[ I = -qAD_p \left. \frac{dP_n(x)}{dx} \right|_{x=0} = \frac{qAD_p}{L_p} \frac{K_T}{P_{nc} e^{\frac{qV_A}{KT}} \frac{qV_A(t)}{KT}} \]

\[ 95 \]
where \( \left[ L_p^* \right]^2 = \frac{D_p q}{1 + j \omega \tau_p} = \frac{L_p}{1 + j \omega \tau_p} \) or \( L_p = \frac{L_p}{\sqrt{1 + j \omega \tau_p}} \)

And the admittance is

\[
Y_p = A \frac{q}{kT} \left[ \frac{D_p}{L_p} p_{no} \right] e^{\frac{qV_A}{kT}}
\]

we can find \( Y_n \) for minority carrier \( n \) in the p-region then the total admittance become \( Y = Y_p + Y_n \) or

\[
Y = \frac{qA}{kT} \left[ \frac{D_p}{L_p} p_{no} \sqrt{1 + j \omega \tau_p} + \frac{D_n}{L_n} \eta_p \sqrt{1 + j \omega \tau_n} \right] e^{\frac{qV_A}{kT}}
\]

the real part of the above equation is conductance \( G_s \), and the imaginary part is \( \omega C_D \), where \( C_D \) is the diffusion capacitance.

If \( \omega \to \infty \), then the low-frequency conductance, \( G_0 \)

\[
Y \bigg|_{\omega \to \infty} = \frac{qA}{kT} \left[ \frac{D_p}{L_p} p_{no} e^{\frac{qV_A}{kT}} \right] = G_0
\]

And

\[
Y \approx G_0 \sqrt{1 + j \omega \tau_p}
\]

for \( \omega \tau_p \ll 1 \) we can simplify

\[
Y \approx G_0 \left( 1 + \frac{\omega \tau_p}{2} \right)
\]

where \( G_0 = \frac{q}{kT} \left[ \frac{qA}{L_p} p_{no} e^{\frac{qV_A}{kT}} \right] = \frac{q}{kT} (I + I_0) = \frac{dI}{dV_A} \)

which is the same as reverse bias conductance and can be simplified as \( G_0 = \frac{I}{V_T} \) or \( V_d = \text{dynamic resistance} = \frac{V_T}{I} \)

and from

\[
\text{Imag}(Y) = G_0 \frac{\omega \tau_p}{2} = \omega \cdot G_0 \tau_p
\]

\[
C_D = \text{Diffusion Capacitance} = \frac{G_0 \tau_p}{2}
\]

\[
C_D = \frac{I}{V_T} \cdot \frac{\tau_p}{2}
\]

\( \tau_p \) = minority carrier life time

To summarize the equivalent model of the diode.
\[ R_s = \text{bulk & contact resistance} \approx \frac{\Delta V_A}{\Delta I} \]

\[ R_d = \frac{V_T}{I} = \text{dynamic resistance} = \frac{\Delta V_A}{\Delta I} \]

\[ C_j(@V_j) = C_j(0) \frac{V_j}{V_{bi}} \sqrt{1 - \frac{V_j}{V_{bi}}} \]  

\[ C_D = \frac{I}{V_T} \cdot \frac{\varepsilon_p}{2} \]

\[ I = I_o \left( e^{\frac{V_A}{n_1 V_T}} - 1 \right) + q \frac{A n_1}{2 \varepsilon_c} \left( e^{\frac{q V_A}{n_2 V_T}} - 1 \right) \]

\[ I_o = q A m_\Delta^2 \left[ \frac{D_N}{L_N N_A} + \frac{D_P}{L_P N_D} \right] \quad \eta_1 \approx 1 \quad \eta_2 \approx 2 \]