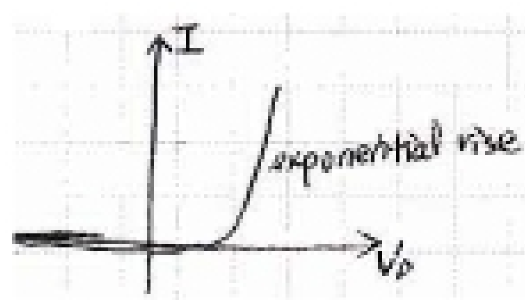
Recitation 16: Small Signal Model of p-n Diode

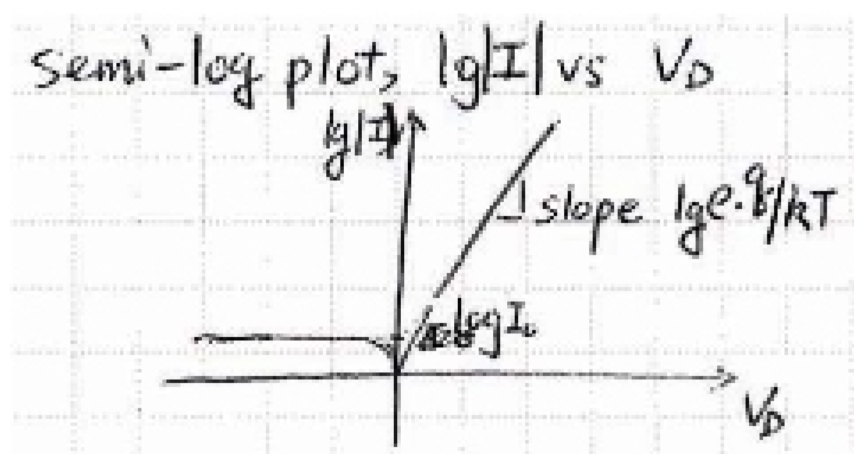
Review

Last week we learned about the IV characteristic of p-n diode:

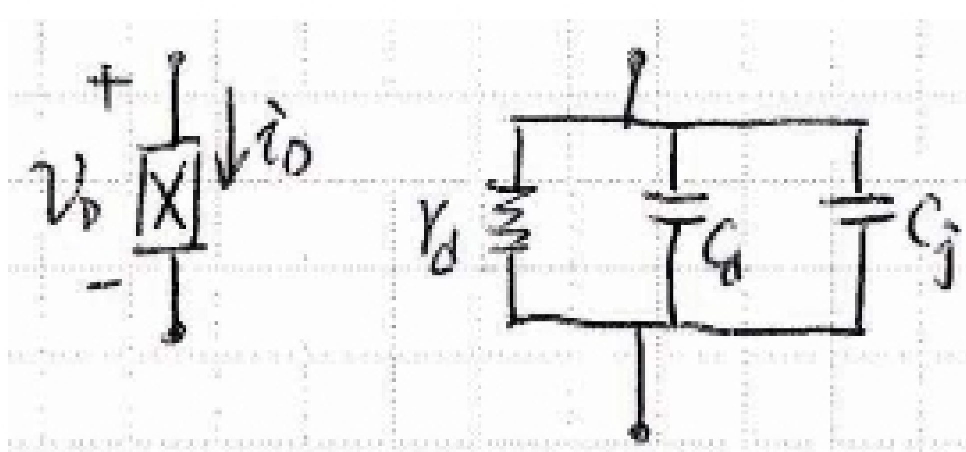
$$I = I_o(e^{qV_a/kT} - 1)$$
$$\text{where } I_o = qAn_i^2\left(\frac{1}{N_a}\frac{D_n}{w_p - x_p} + \frac{1}{N_d}\frac{D_p}{w_n - x_n}\right)$$

If we plot,

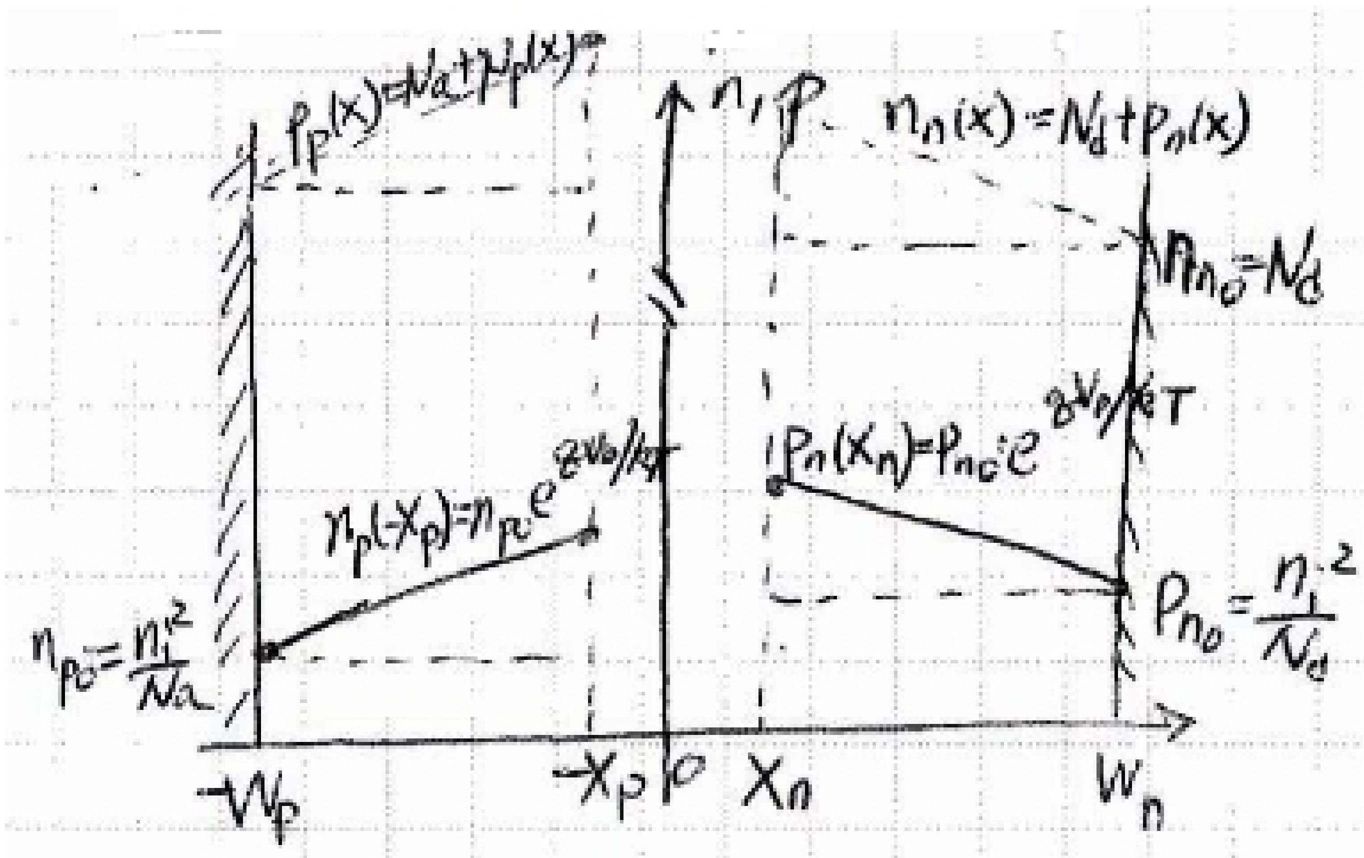




Yesterday, we discussed the small signal model for p-n diode. Under forward bias, the small signal (ss) model of a p-n diode is:

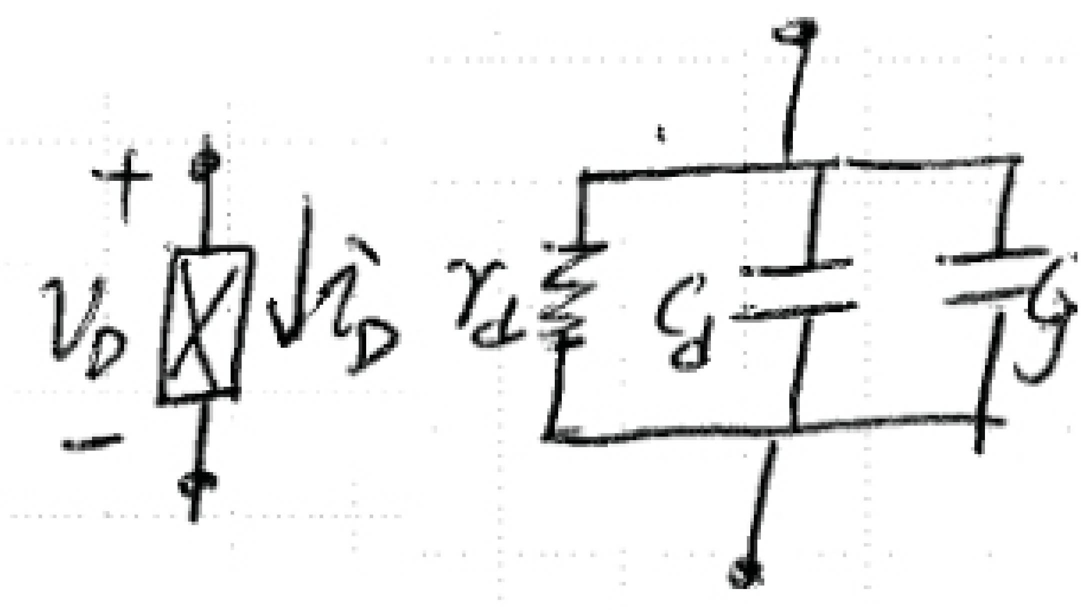


C_j is the junction capacitance as we talked about before, C_d is called "diffusion capacitance", this is new



Small signal circuit model of p-n diode: (two terminal device)

In a small signal model, we have linearized conductance (resistance) and capacitances.



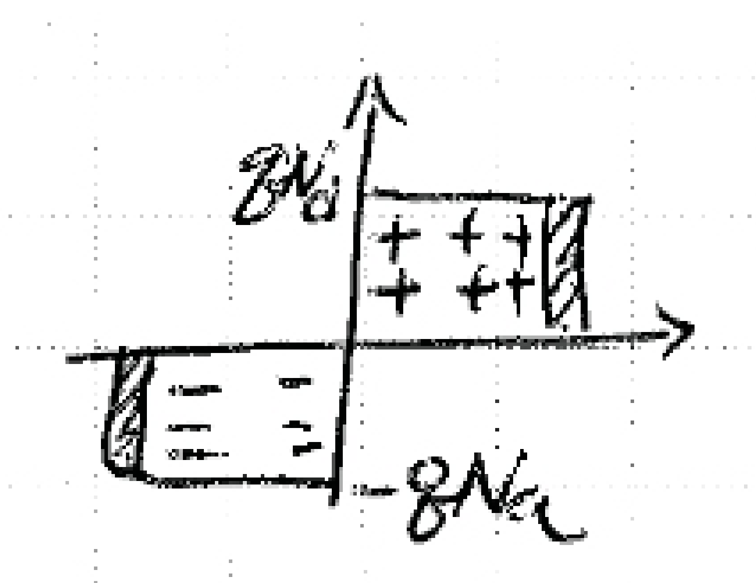
Linearized Conductance (Resistance)

$$
\begin{aligned}
\gamma_{\rm d} &= \frac{1}{g_{\rm d}}, \quad g_{\rm d} = \frac{\delta i_{\rm D}}{\delta V_{\rm D}}\bigg|_{V_{\rm D}} = \frac{\delta I_{\rm o} \cdot (e^{qV_{\rm D}/kT} - 1)}{\delta V_{\rm D}}\bigg|_{V_{\rm D}} \\
&= I_{\rm o} \cdot \frac{q}{kT} e^{qV_{\rm D}/kT} \\
&= \frac{q}{kT} \cdot (I_{\rm D} + I_{\rm o}) \\
&= \frac{q}{kT} I_{\rm D}, \quad \frac{kT}{q} = V_{\rm th} \\
\Longrightarrow \gamma_{\rm d} &= \frac{V_{\rm th}}{I_{\rm D}}
\end{aligned}
$$

$V_{\rm th}$ constant, the larger operating current $I_{\rm D}$, the smaller is $\gamma_{\rm d}$

Depletion Capacitance (due to p-n junction)

$$
\begin{aligned}
C_{\rm jo} &= \frac{\epsilon_{\rm s}}{x_{\rm do}} = \sqrt{\frac{q\epsilon_{\rm s} N_{\rm a} N_{\rm d}}{2(N_{\rm a} + N_{\rm d})\phi_{\rm B}}} \\
C_{\rm j}(V_{\rm D}) &= \frac{C_{\rm jo}}{\underbrace{\sqrt{1 - \frac{V_{\rm D}}{\phi_{\rm B}}}}_{\text{capacitance/unit area!}}} \quad \text{For forward bias limit } V_{\rm D} \text{ to } \frac{\phi_{\rm B}}{2}
\end{aligned}
$$



Diffusion Capacitance

For this, we need to look at the majority carrier concentration as well. To keep quasi-neutral,

$$
\begin{aligned}
n_{\rm n}(x) &= N_{\rm d} + p_{\rm n}(x) \\
p_{\rm p}(x) &= N_{\rm a} + n_{\rm p}(x)
\end{aligned}
$$