Last Time:

p-n junction in Equilibrium
band diagram
Charges: $\mathcal{E}$-field
Potential $V(x) \rightarrow$ bands

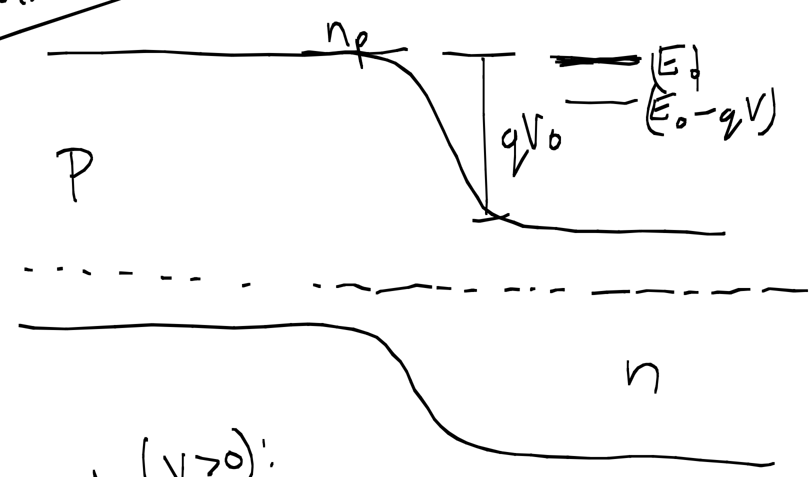
This Time:

Currents under bias
Voltage (V) $\rightarrow$ Current (I)
I-V curve

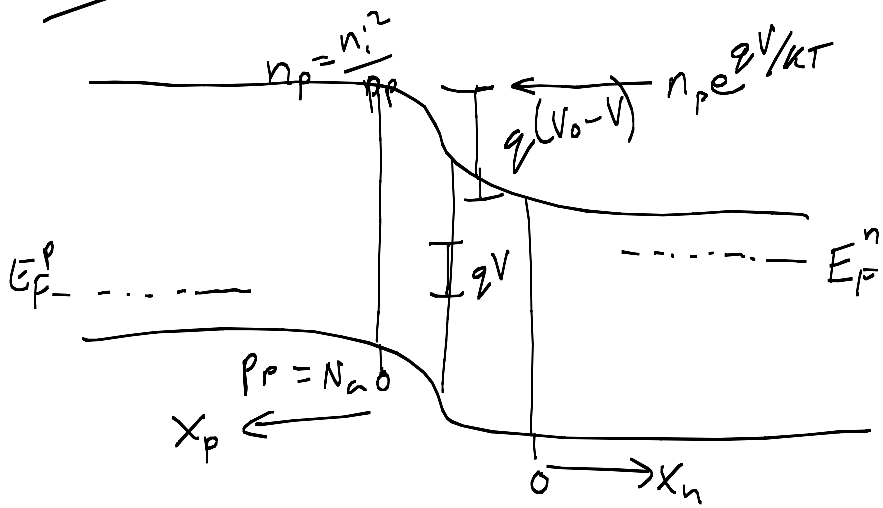
10/25	Dr. Jang: AC pn junctn
10/30	Xu Jing: Capacitance
11/1	Prof. Zide: heterojunct
11/6	Prof. Cloutier: PV/LED
11/8	Cancelled
11/13	REVIEW
11/15	Quiz 3

Band diagram in "forward" (n-side @ 0V)

equilibrium:



forward $(V>0)$:



Boltzmann distribution:

$$f \propto e^{-\frac{E - E_F}{k_B T}}$$

$$e^{qV/k_B T}$$

barrier is lowered, so states with higher occupancy probability can couple to other side across depletion region

Minority carrier injection: Boundary conditions

p-side $\longrightarrow$ $\delta n(0) = n_p e^{qV/kT} - n_p$

$$= n_p\left(e^{qV/kT} - 1\right) = \Delta n$$

n-side $\quad \delta p(0) = p_n\left(e^{qV/kT} - 1\right) = \Delta p$

$$n = \delta n + n_0$$

$$\delta n = n - n_0$$

$$\frac{\partial \delta n}{\partial t} = D_n \frac{\partial^2 \delta n}{\partial x^2} - \frac{\delta n}{\tau_n}$$

$$0 = D_n \delta n'' - \frac{\delta n}{\tau_n}$$

$$\delta n'' = \frac{\delta n}{D_n \tau_n}$$

$$\delta n(x_p) = A e^{\frac{x_p}{\sqrt{D_n \tau_n}}} + B e^{-\frac{x_p}{\sqrt{D_n \tau_n}}}$$

Apply BC's

$$\delta n(0) = \Delta n$$

$$\delta n(\infty) = 0$$

$$A = 0, \quad B = \Delta n$$

$$\delta n(x_p) = \Delta n e^{-\frac{x_p}{\sqrt{D_n \tau_n}}}$$

$$\delta p(x_n) = \Delta p e^{-\frac{x_n}{\sqrt{D_p \tau_p}}}$$

Current density

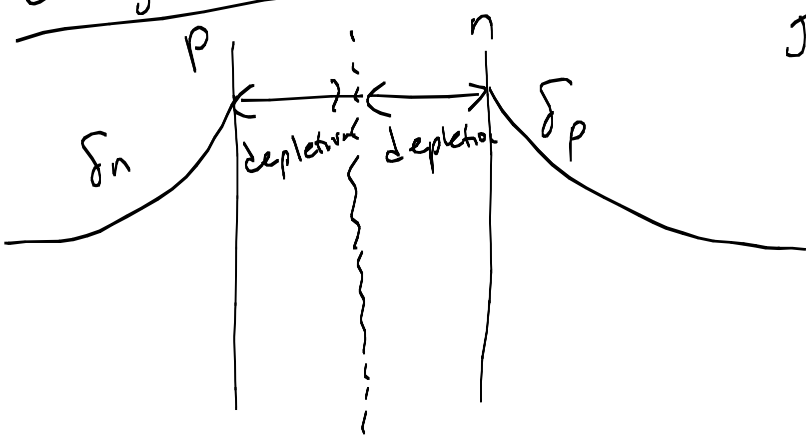
diffusion:

$$J_n = qD_n \frac{d\delta_n}{dx_p} = -q\frac{D_n \Delta n}{\sqrt{D_n \tau_n}} e^{\frac{-x_p}{\sqrt{D_n\tau_n}}} \xrightarrow{x_p=0} -q\sqrt{\frac{D_n}{\tau_n}}\Delta n \xrightarrow[\text{as } -x]{x_p \text{ is in same dir}} \underline{q\sqrt{\frac{D_n}{\tau_n}}\Delta n}$$

$$J_p = -qD_p \frac{d\delta p}{dx_n} = q\frac{D_p \Delta p}{\sqrt{D_p \tau_p}} e^{\frac{-x_n}{\sqrt{D_p\tau_p}}} \xrightarrow{x_n=0} q\sqrt{\frac{D_p}{\tau_p}}\Delta p$$

$$J = J_n + J_p = q\left(\sqrt{\frac{D_n}{\tau_n}} n_p + \sqrt{\frac{D_p}{\tau_p}} p_n\right)\left(e^{qV/kT}-1\right)$$ "Ideal diode eqn."

Charge control:



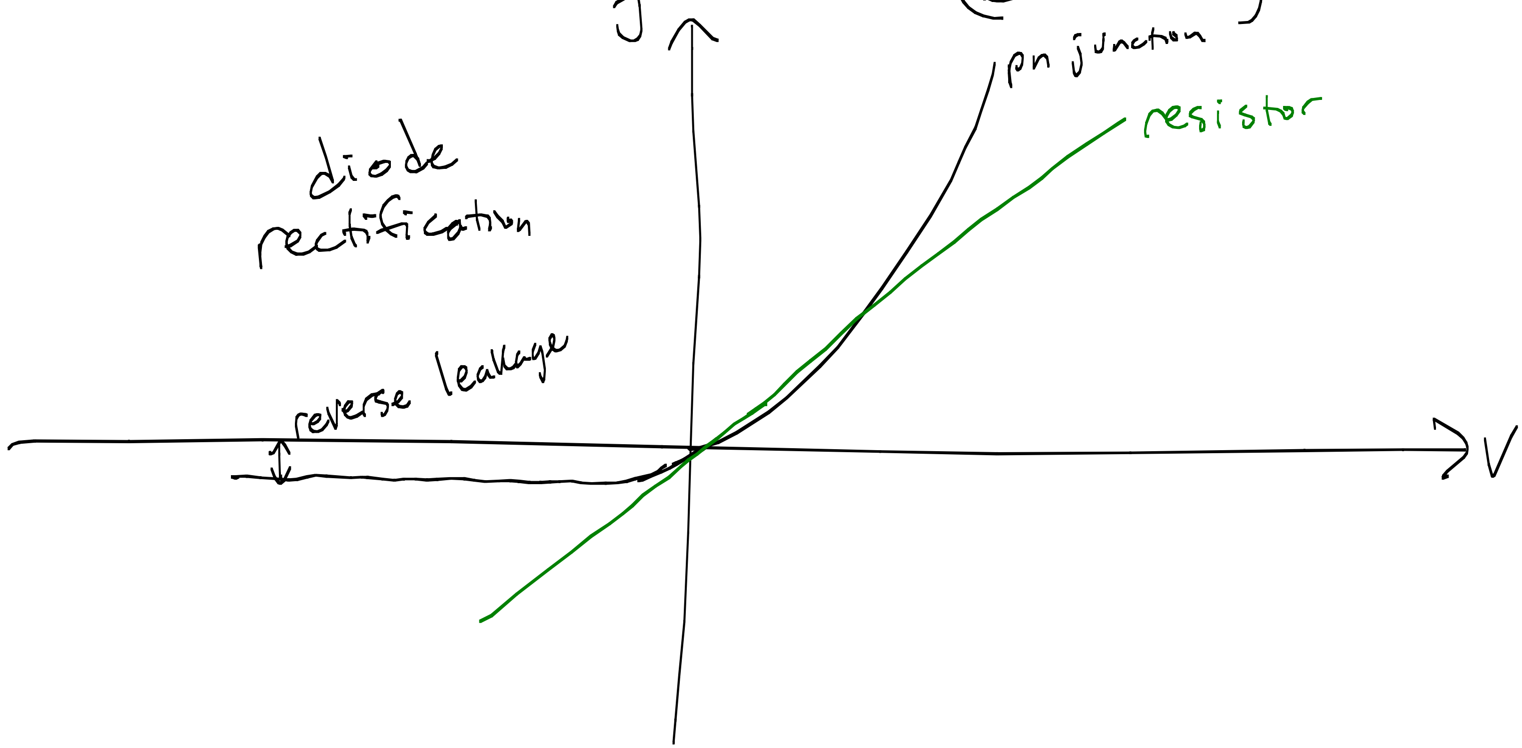
$$J_n = \frac{Q_n}{\tau_n}$$

$$Q = (-q)\int_0^\infty \Delta n\, e^{-\frac{x_p}{\sqrt{D_n\tau_n}}} dx_p$$
$$= +q\Delta n\sqrt{D_n\tau_n}\; e^{-\frac{x_p}{\sqrt{D_n\tau_n}}}\Big|_0^\infty$$
$$= -q\Delta n\sqrt{D_n\tau_n}$$

$$J_n = q\frac{\sqrt{D_n\tau_n}}{\tau_n}\Delta n = \underline{q\sqrt{\frac{D_n}{\tau_n}}\Delta n}$$

Ideal diode equation

$$J \propto \left(e^{qV/kT} - 1\right)$$



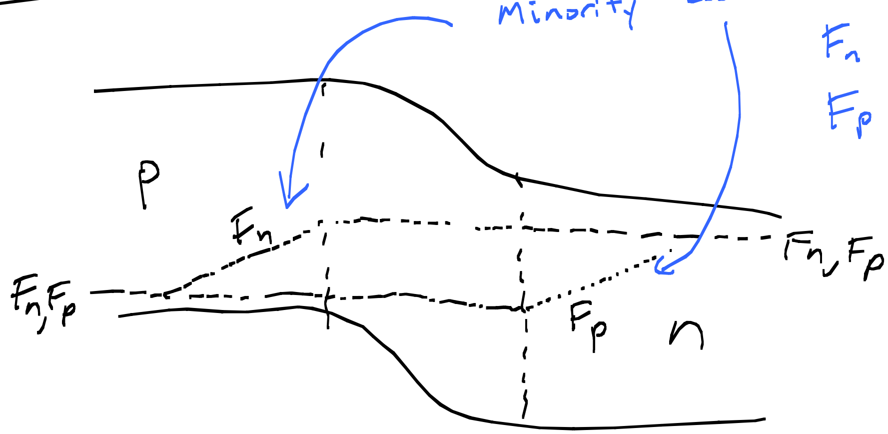
Quasi Fermi levels

forward:

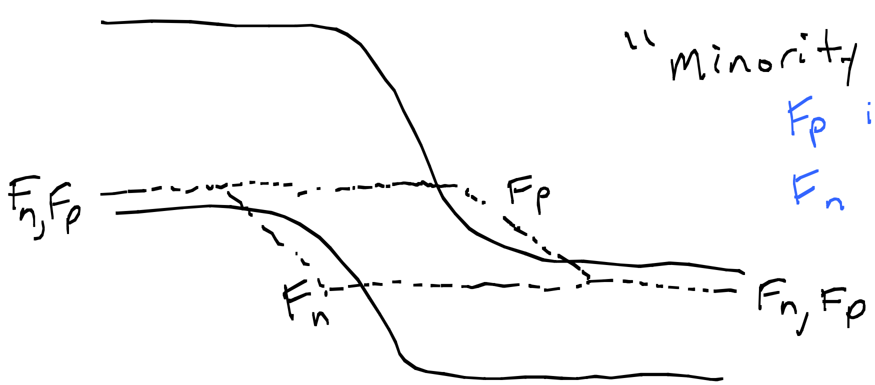
minority carrier injection

F_n closer to E_c on p-side

F_p closer to E_v on n-side



reverse:



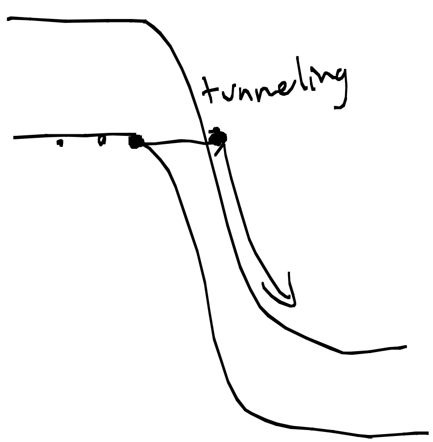
"minority carrier extraction"

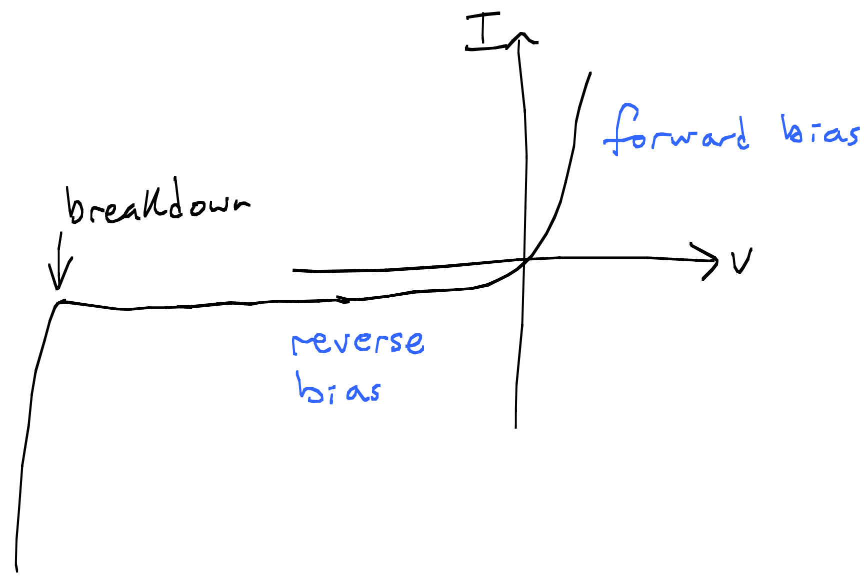
F_p is far from E_v on n-side

F_n is far from E_c on p-side

Reverse bias: Breakdown

Zener: heavily-doped p-n





Avalanche: