Section 23
Schottky Diode

23.2 Physical Processes

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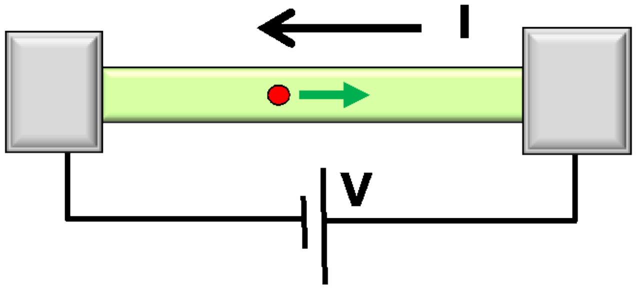
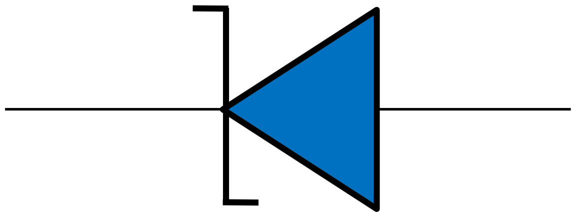
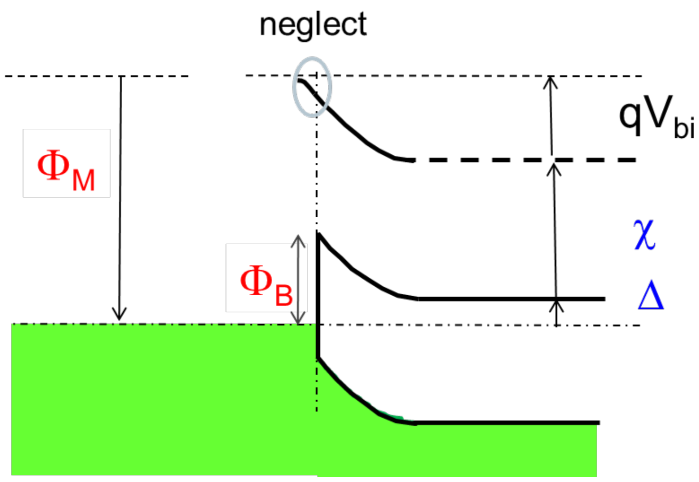


I = G × V

= q × n × v × A

charge density velocity area





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  - »AC and Large Signal Response
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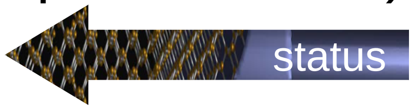
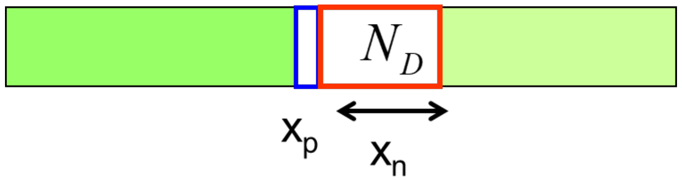




Video

Video

Video

$$J_T = J_{s\to m}(0) - J_{s\to m}(V_A) = \frac{q n_m \upsilon_{th}}{2} e^{\frac{-q\Phi_B}{kT}}\left[e^{\frac{qV_A}{kT}} - 1\right]$$

Energy Resolved Thermionic Flux

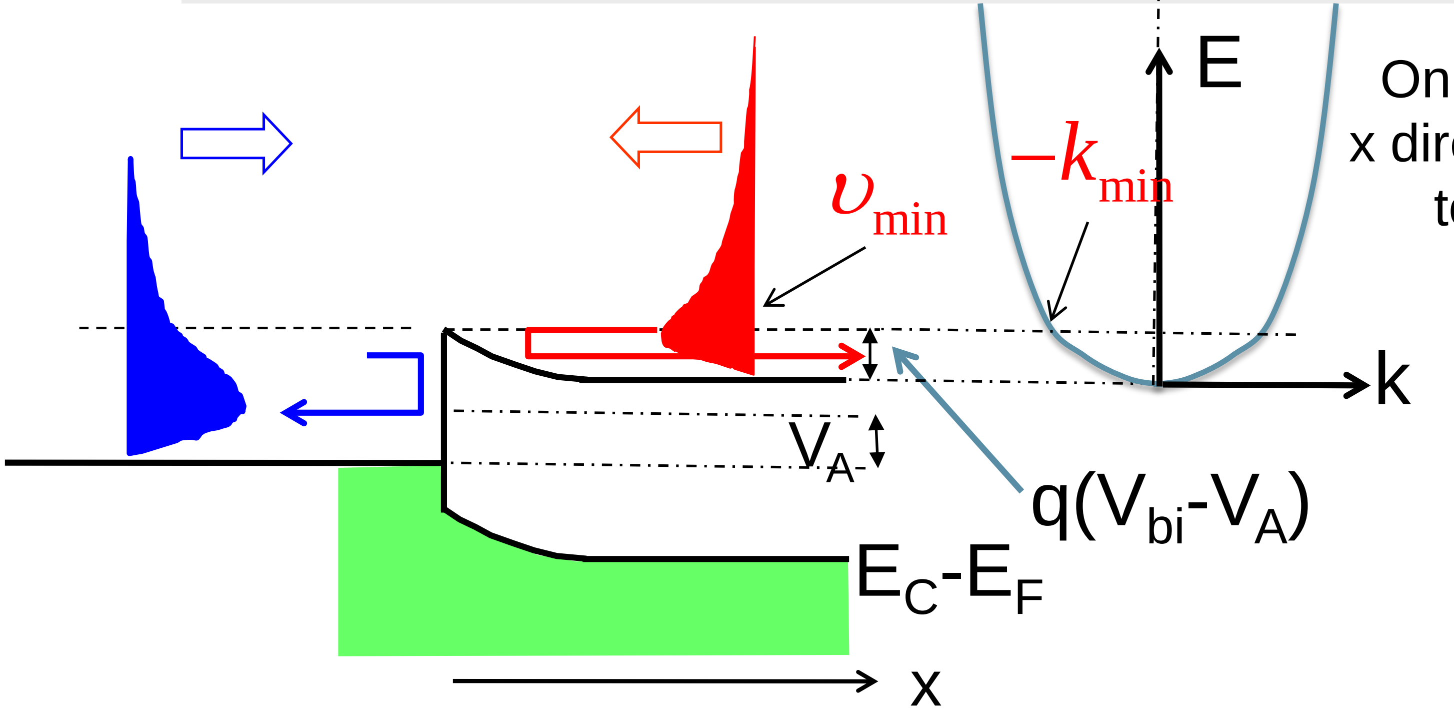
Energy $< \frac{1}{2} m^* \upsilon_{min}^2$ will be bounced back

~ DOS

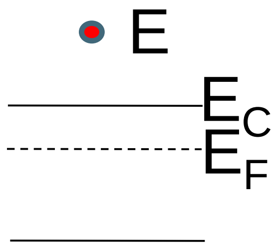
Occupation (non-denegerate)

$$J_{s\to m} = -q \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{-k_{min}} \frac{\Omega}{4\pi^3} dk_x dk_y dk_z \; e^{-(E-E_F)\beta} \; \upsilon_x$$

Only movement in the x direction will contribute to the current flux



Thermionic Flux from Semi to Metal ..



$$J_{s\to m} = -q\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{-k_{\min}} \frac{\Omega}{4\pi^3} dk_x dk_y dk_z \, e^{-(E-E_F)\beta}\, \upsilon_x$$

$$E - E_F = (E - E_C) + (E_C - E_F) = \frac{1}{2}m^*\upsilon_x^2 + \frac{1}{2}m^*\upsilon_y^2 + \frac{1}{2}m^*\upsilon_z^2 + (E_C - E_F)$$

$$= qe^{-(E_c - E_F)\beta}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{-\upsilon_{\min}} \frac{\Omega}{4\pi^3}\frac{d(m^*\upsilon_x)}{\hbar}\frac{d(m^*\upsilon_y)}{\hbar}\frac{d(m^*\upsilon_z)}{\hbar} e^{-\frac{(m\upsilon_x^2 + m\upsilon_y^2 + m\upsilon_z^2)}{2}\beta}\upsilon_x$$

$$J_{s\to m} = \frac{q\Omega(m^*)^3}{4\pi^3\hbar^3} e^{-(E_c - E_F)\beta}\left[\int_{-\infty}^{\infty} e^{-\left(\frac{m^*\upsilon_y^2}{2}\right)\beta} d\upsilon_y\right]\left[\int_{-\infty}^{\infty} e^{-\left(\frac{m^*\upsilon_z^2}{2}\right)\beta} d\upsilon_z\right]\left[\int_{-\infty}^{-\upsilon_{\min}} d\upsilon_x e^{-\left(\frac{m^*\upsilon_x^2}{2}\right)\beta}\upsilon_x\right]$$

Thermionic Current ...

$$\upsilon_{\min} = \sqrt{\frac{2q}{m^*}\left(V_{bi} - V_A\right)}$$

$$J_{s\to m} = \frac{q\Omega\left(m^*\right)^3}{4\pi^3\hbar^3} e^{-(E_c - E_F)\beta} \left[\int_{-\infty}^{\infty} e^{-\left(\frac{m^*\upsilon_y^2}{2}\right)\beta} d\upsilon_y\right] \left[\int_{-\infty}^{\infty} e^{-\left(\frac{m^*\upsilon_z^2}{2}\right)\beta} d\upsilon_z\right] \left[\int_{-\infty}^{-\upsilon_{\min}} d\upsilon_x e^{-\left(\frac{m^*\upsilon_x^2}{2}\right)\beta} \upsilon_x\right]$$

$$\downarrow \qquad\qquad \downarrow \qquad\qquad \downarrow$$

$$\sqrt{\pi} \qquad\qquad \sqrt{\pi} \qquad\qquad \frac{1}{2} e^{-q(V_{bi} - V_A)\beta}$$

$$J_{s\to m} = \frac{4\pi q m^* k^2}{h^3} T^2 e^{(E_F - E_C - qV_{bi})\beta} e^{qV_A\beta} = A_0 e^{qV_A\beta}$$

$$J_T = J_{s\to m} - J_{m\to s} = A_0\left(e^{qV_A\beta} - 1\right)$$

Some insight of the Thermionic Current …

Compare to the current of p-n diodes…

$$J_T = J_{s\to m} - J_{m\to s} = A_0\left(e^{qV_A\beta} - 1\right)$$ Schottky diode

$$J_T = -q\left[\frac{D_n}{W_p}\frac{n_i^2}{N_A} + \frac{D_p}{W_n}\frac{n_i^2}{N_D}\right]\left(e^{qV_A\beta} - 1\right)$$ p-n diode

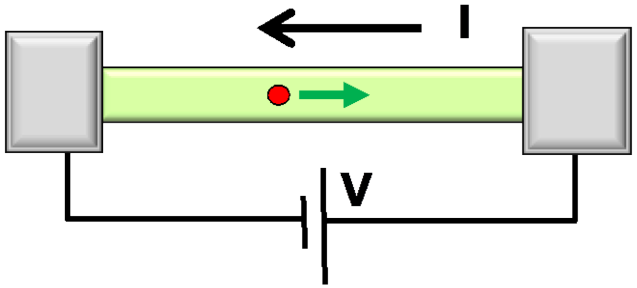
Both of them depends exponentially on V_A, however current of p-n diodes depends more on temperature (since n_i depends strongly on E_g), where the Schottky diode doesn't have that dependence.

However, E_g hides in…

$$J_{s\to m} = \frac{4\pi q m^* k^2}{h^3} T^2 e^{(E_F - E_C - qV_{bi})\beta} e^{qV_A\beta} = A_0 e^{qV_A\beta}$$

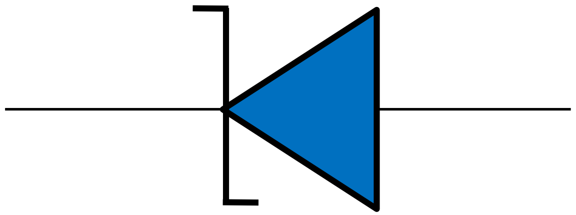
The information of material hides in m*

The information of doping concentration hides in E_F-E_C



$$I = G \times V = q \times n \times v \times A$$

charge density velocity area



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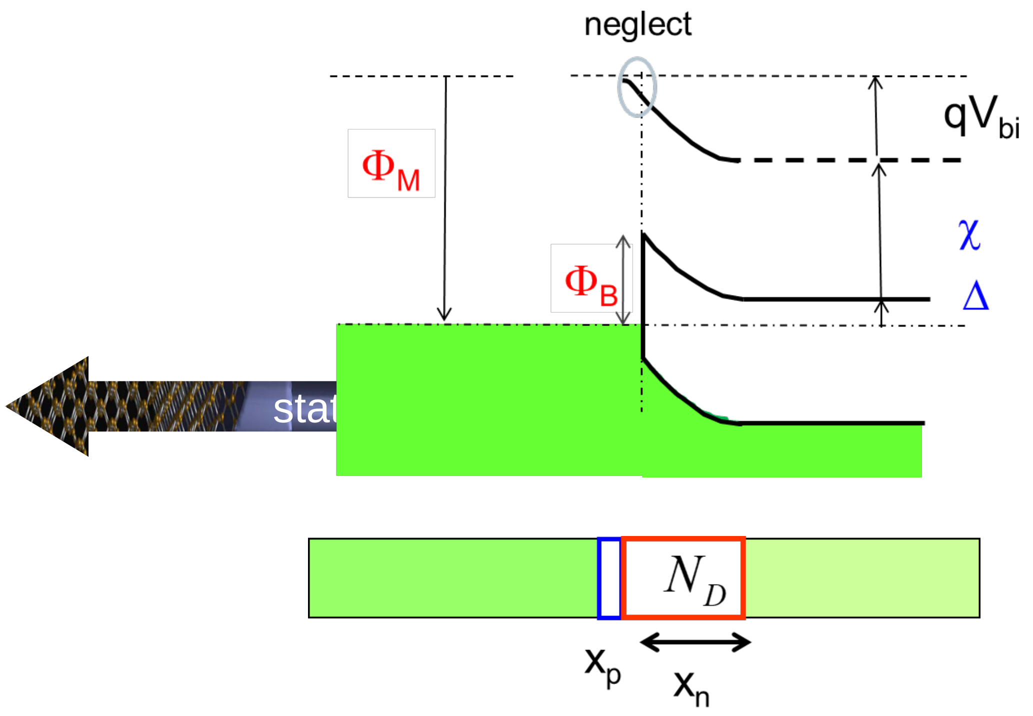

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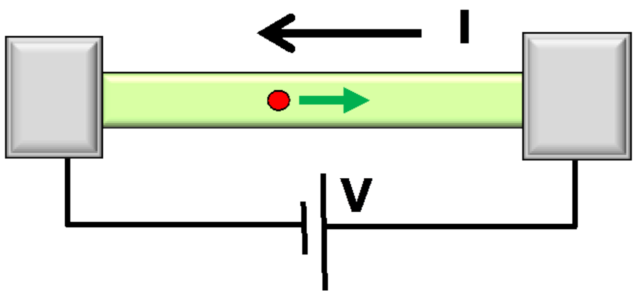
Section 23
Schottky Diode



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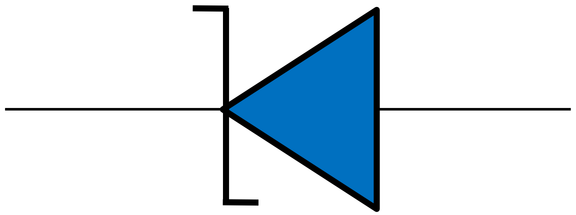

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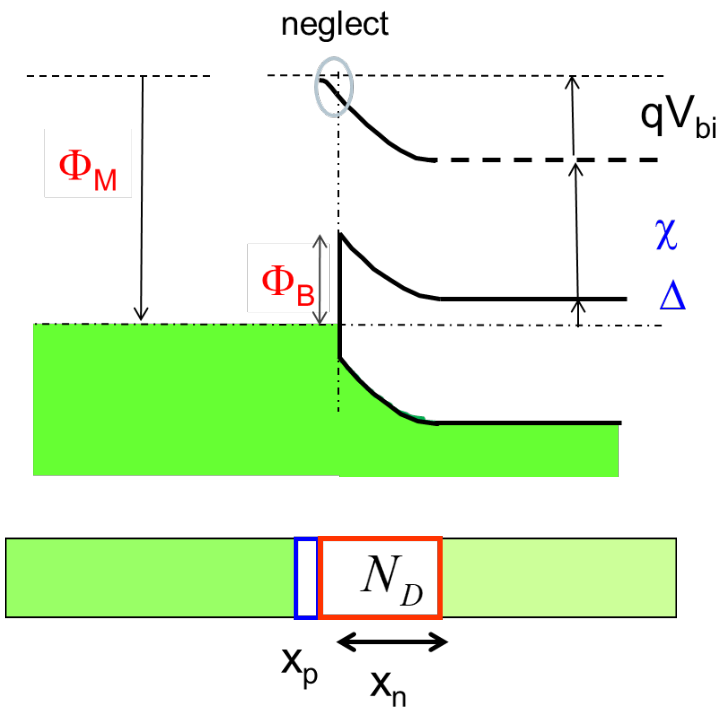

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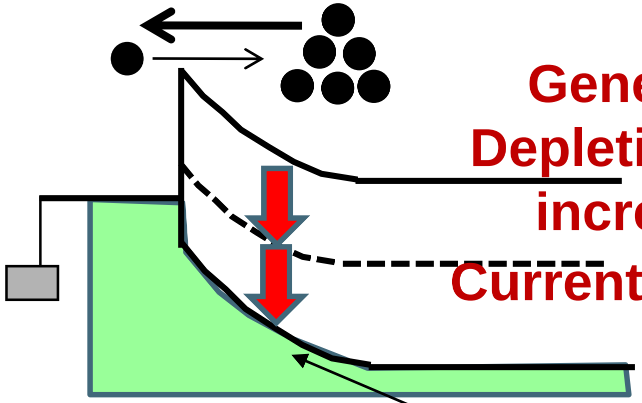
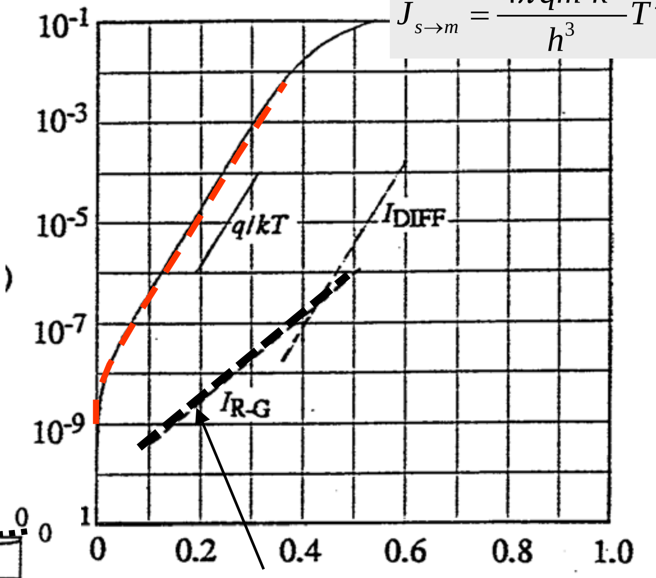
Recombination/Generation/Impact-ionization

$$J_{s\to m} = \frac{4\pi q m^* k^2}{h^3} T^2 e^{(E_F - E_C - qV_{bi})\beta} e^{qV_A\beta} = A_0 e^{qV_A\beta}$$

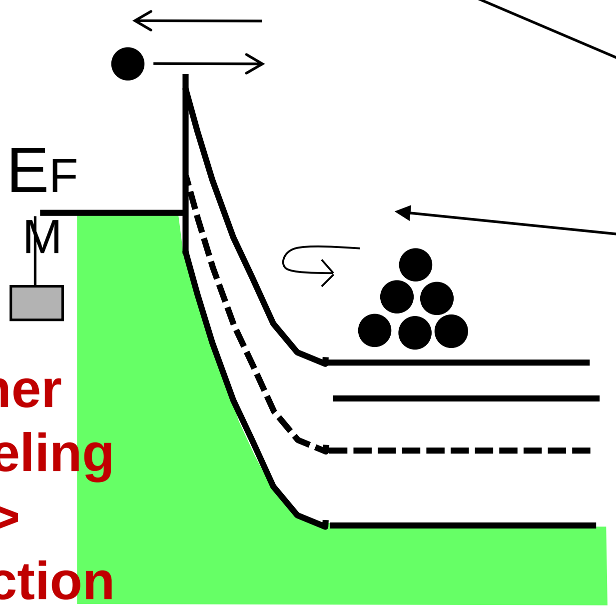


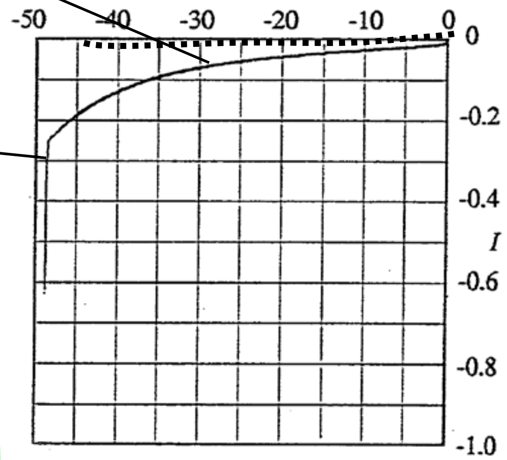
Generation
Depletion width increasing
Current Slope $\sqrt{V}$

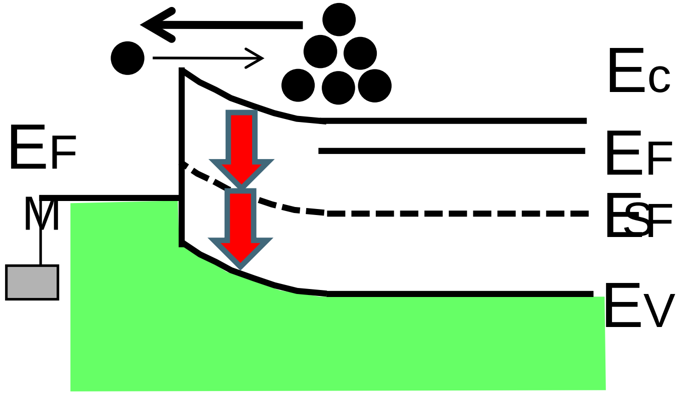


Traps at M-S junction
=> recomb.

Slope ½







Zener Tunneling
=>
Impaction Ionization

$$I = I_o\left(e^{q(V_A - R_S I)\beta/m} - 1\right)$$

SAME technique as in p-n junction except integrate to x_p only
=> ONE sided junction

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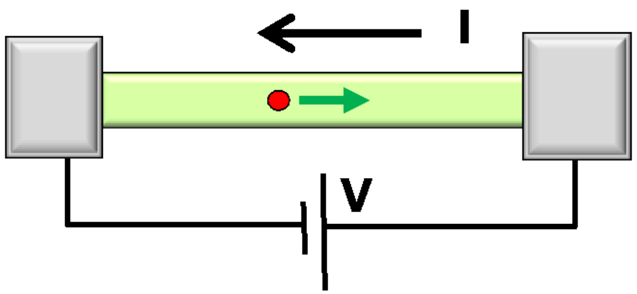

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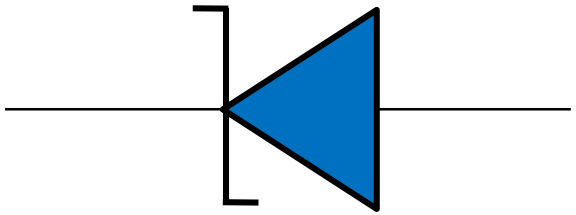

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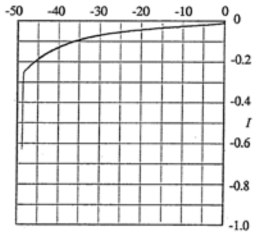

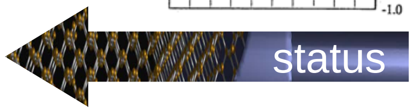

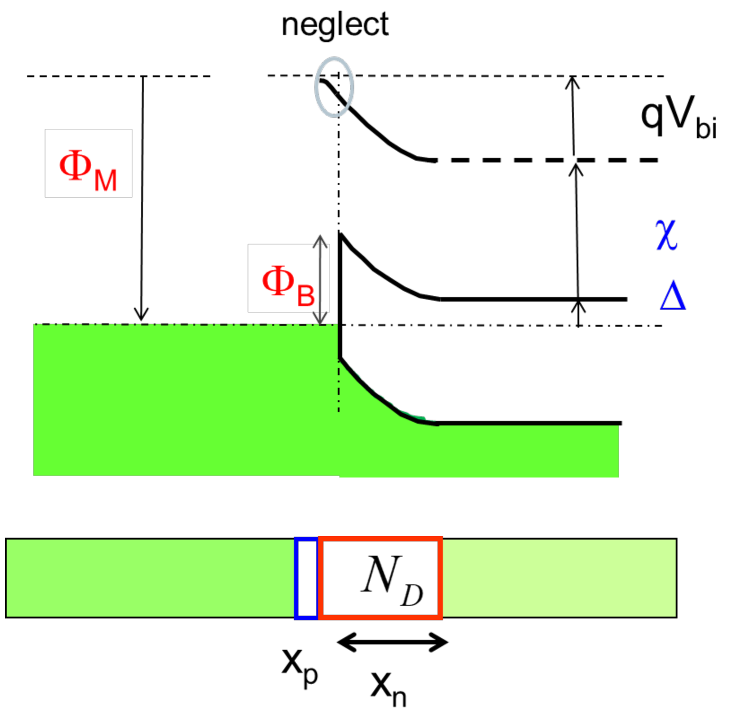

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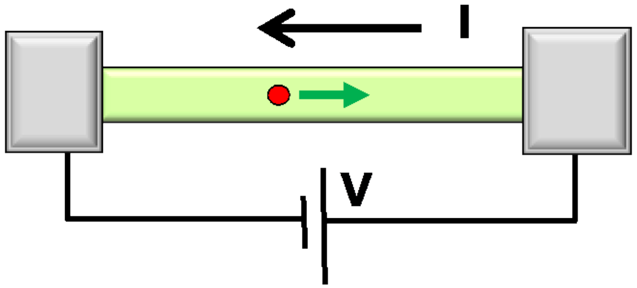

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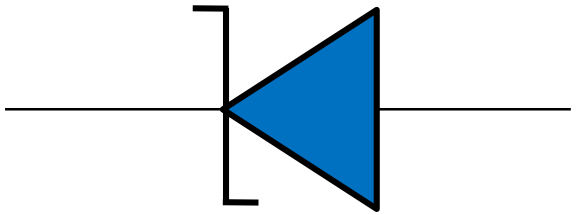

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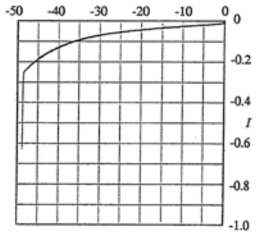

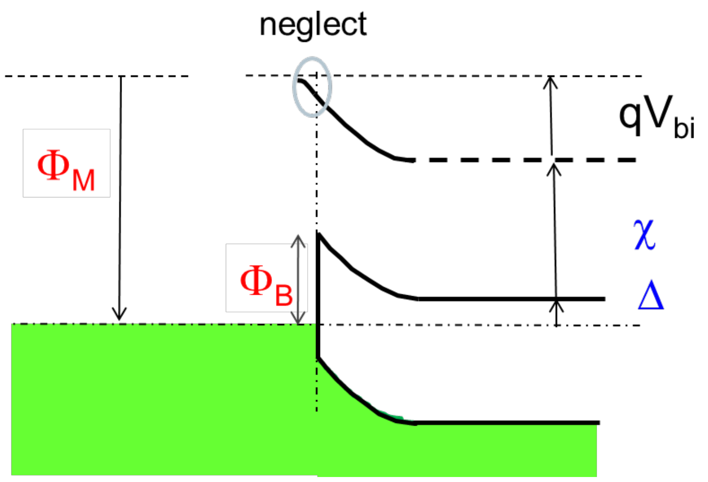

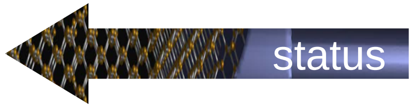

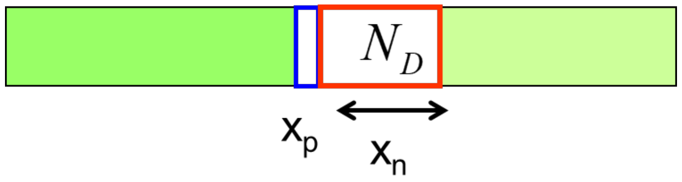

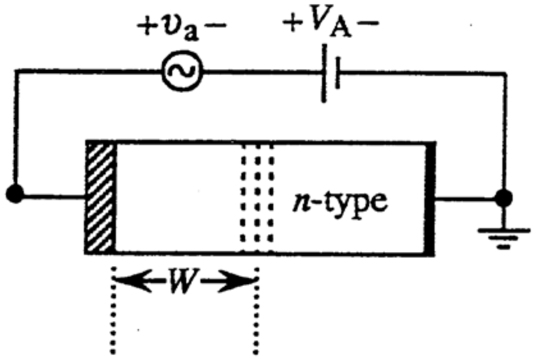

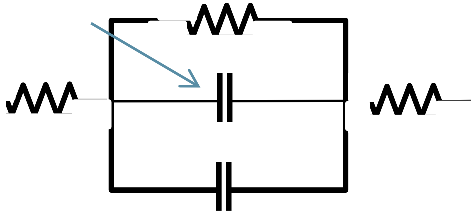

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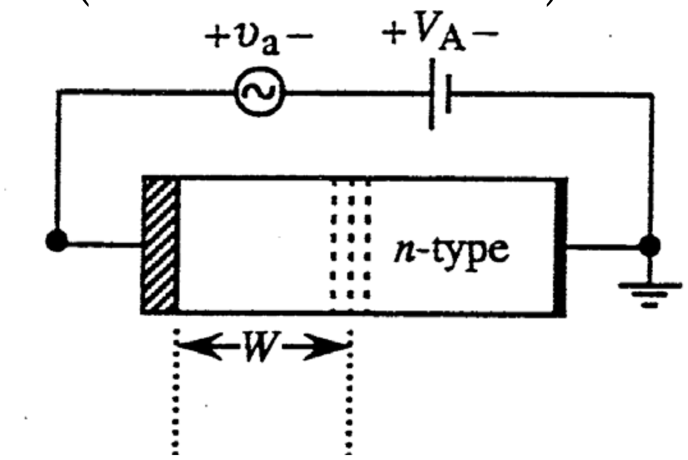
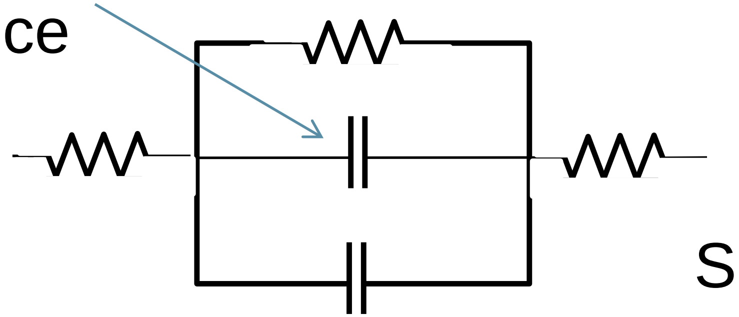
$$I = I_o\left(e^{q(V_A - R_S I)\beta/m} - 1\right)$$

AC response

$$I = I_o\left(e^{q(V_A - R_S I)\beta/m} - 1\right)$$



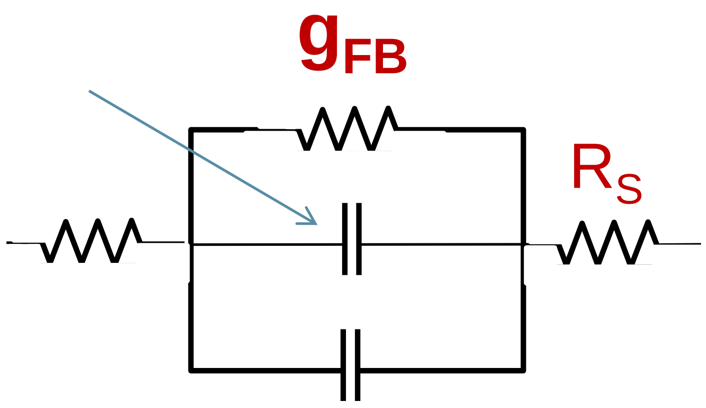


We will not have Diffusion Capacitance here…

Forward Bias Conductance

m depends on which operation regime you are

$$I = I_o\left(e^{q(V_A - R_S I)\beta/m} - 1\right)$$

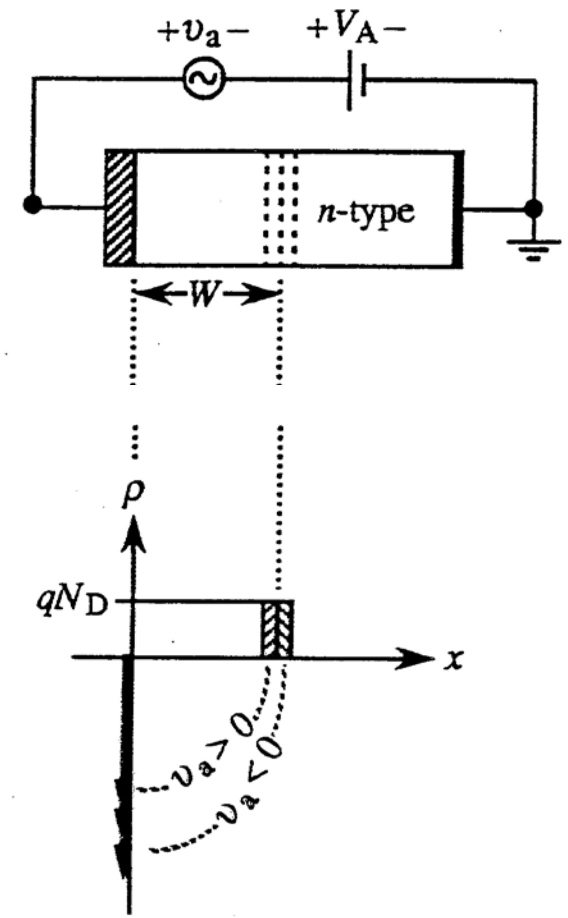


$$\ln\frac{I + I_o}{I_0} = q(V_A - R_S I)\beta/m$$

$$\frac{m}{q\beta\left(I + I_o\right)} = \frac{dV_A}{dI} - R_S$$

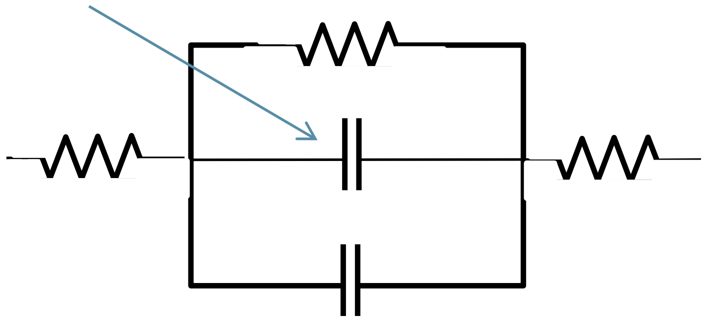
$$\frac{1}{g_{FB}} = R_S + \frac{m}{q\beta(I + I_0)}$$

Junction Capacitance (Majority Carriers)



Response time – dielectric
Very fast propagation

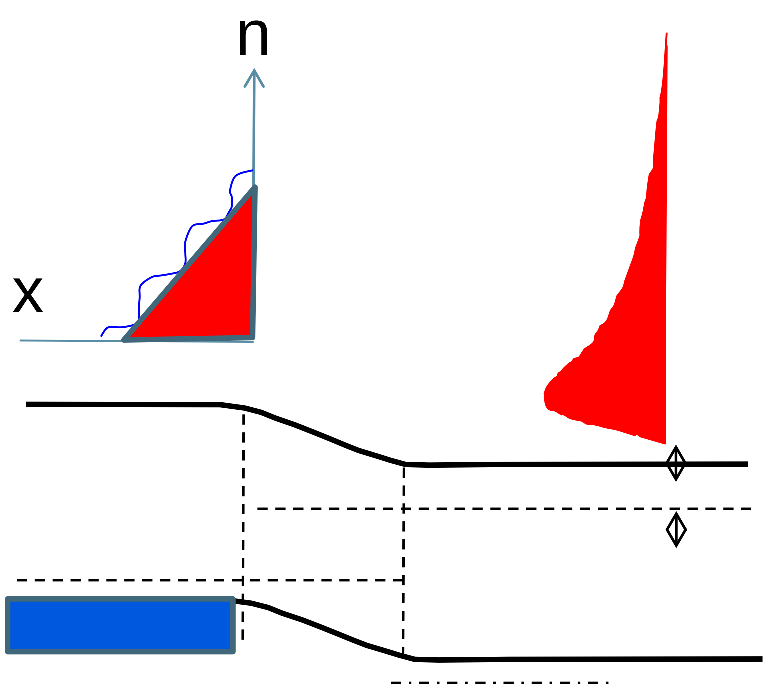
Junction Capacitance



$$C_J = \frac{\kappa_s \varepsilon_0 A}{W}$$

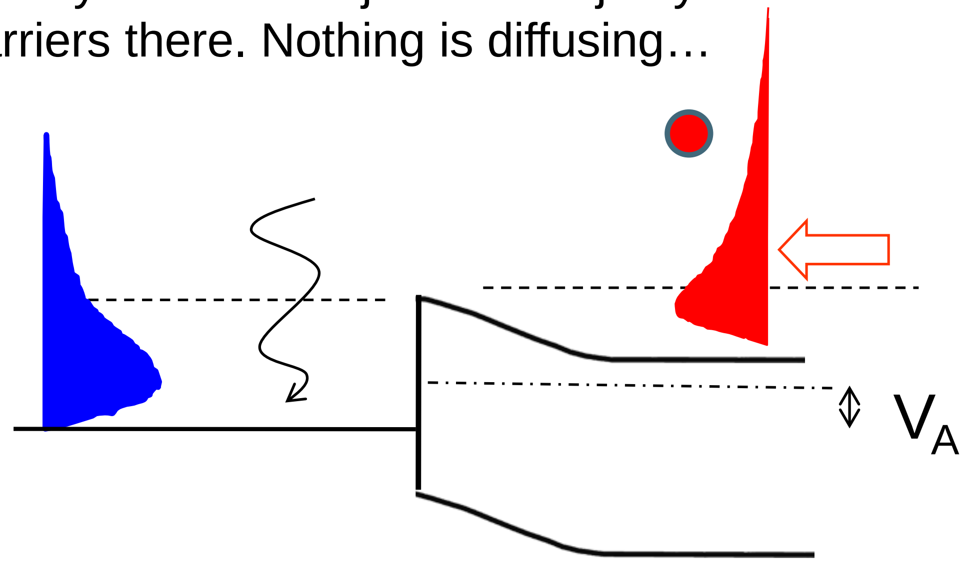
$$C_J = \frac{\kappa_s \varepsilon_0 A}{\sqrt{\frac{2\kappa_s \varepsilon_0}{qN_D}(V_{bi} - V_A)}}$$

p-n Diode



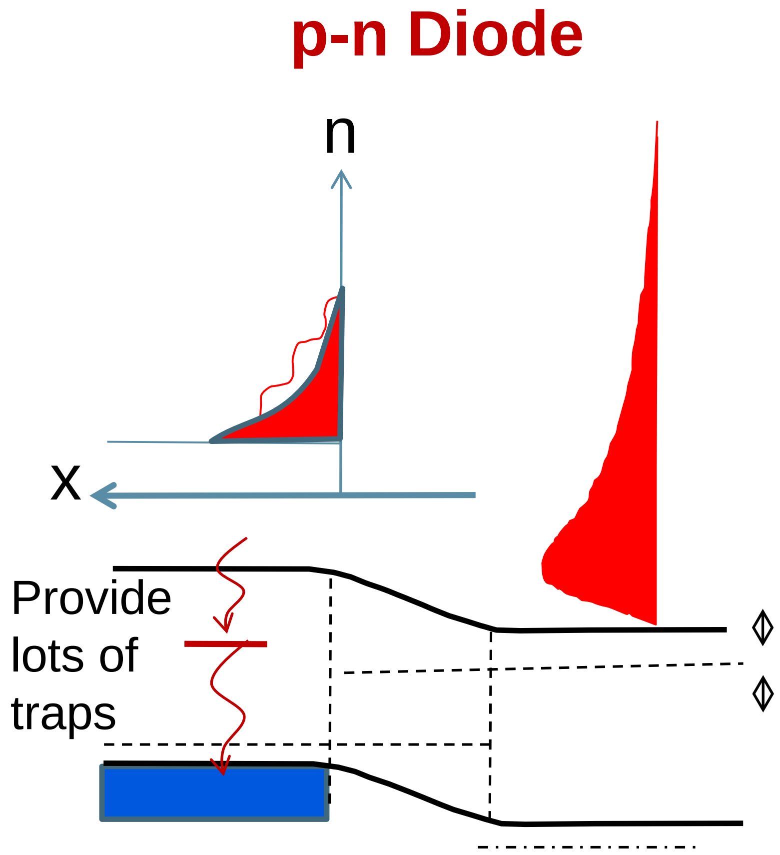
Schottky diode

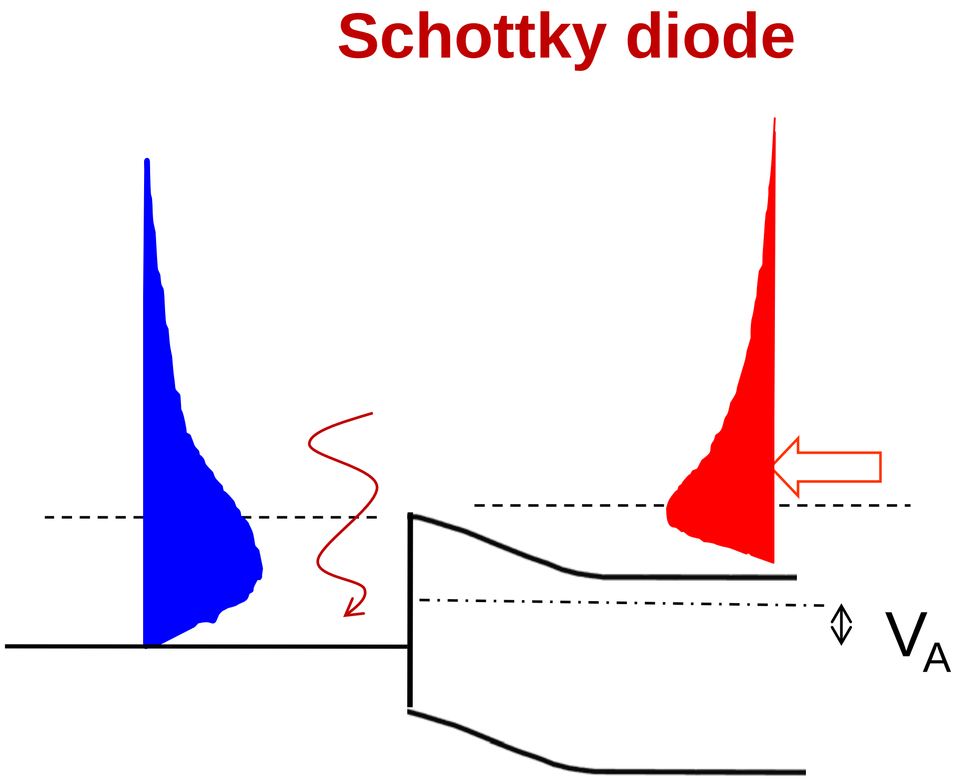
When electrons reach the metal side, they quickly scatter and join the majority carriers there. Nothing is diffusing…



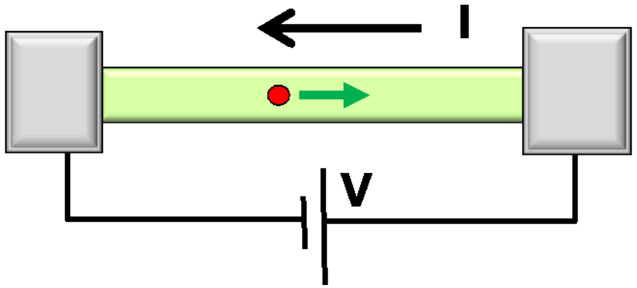
No minority carrier transport and therefore no diffusion capacitance ..

Reducing diffusion capacitance in p-n diode





Short minority carrier lifetime in p-n junction diode equivalent to rapid energy relaxation in SB diode.



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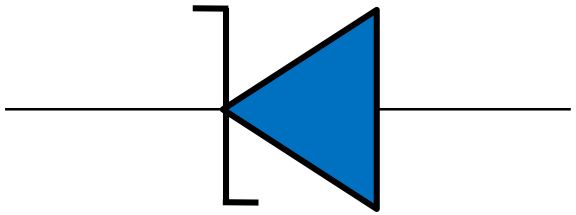

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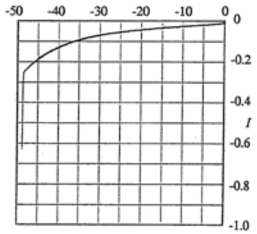

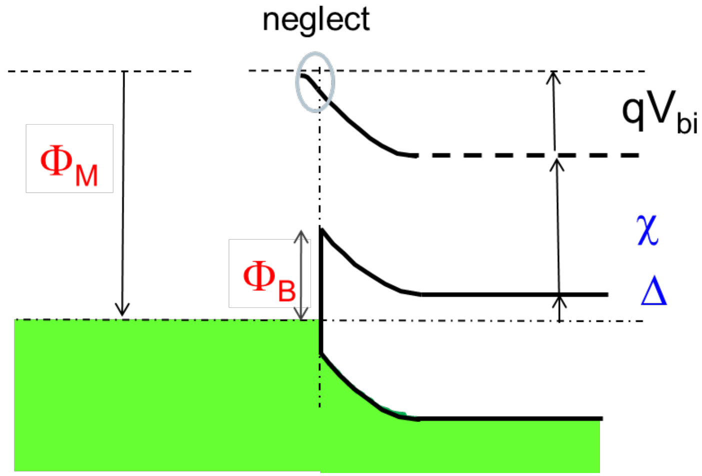

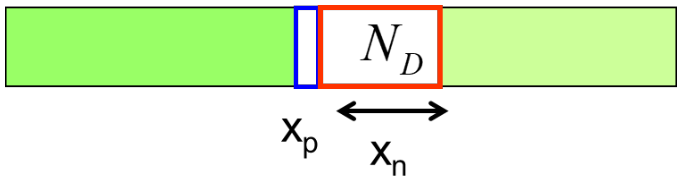

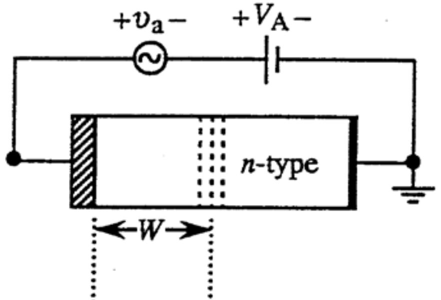

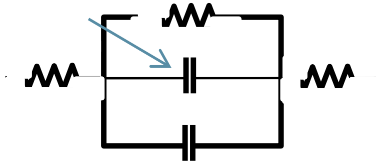

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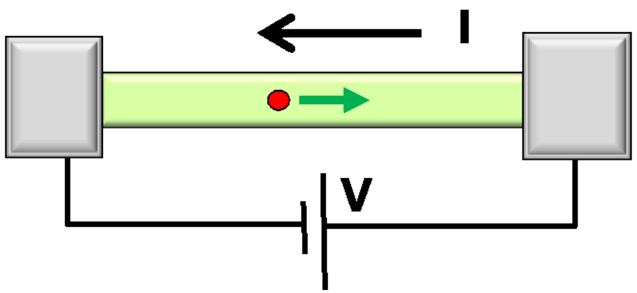
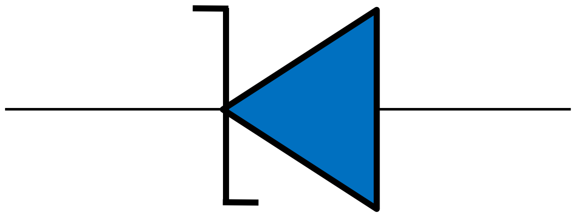
Video
Video

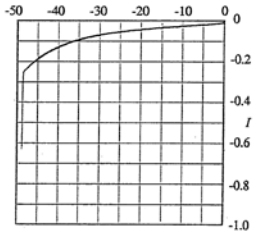


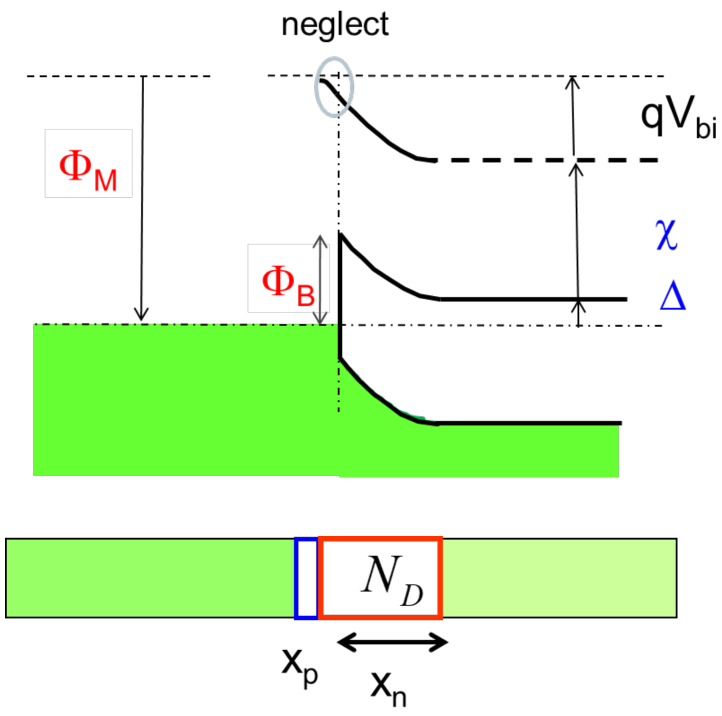
$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area



- 23.1 Basics
  - »Equilibrium band-diagram
  - »DC Thermionic current (simple derivation)
- 23.2 Physical Processes
  - »DC Thermionic current (detailed derivation)
  - »Recombination/Generation/Ionization
  - »AC and Large Signal Response
- 23.4 Practical Issues
  - »Ohmic vs. Schottky Contact
  - »Schottky Barrier Lowering – Image Charges
  - »Fermi Level Pinning





$$J_{s\to m} = \frac{4\pi q m^* k^2}{h^3} T^2 e^{(E_F - E_C - qV_{bi})\beta} e^{qV_A\beta} = A_0 e^{qV_A\beta}$$

$$I = I_o\left(e^{q(V_A - R_S I)\beta / m} - 1\right)$$

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