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ECE606: Solid State Devices
Lecture 26: Schottky Diode (II)

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Outline

1) **DC Thermionic current (detailed derivation)**
2) AC small signal and large-signal response
3) Additional information
4) Conclusions

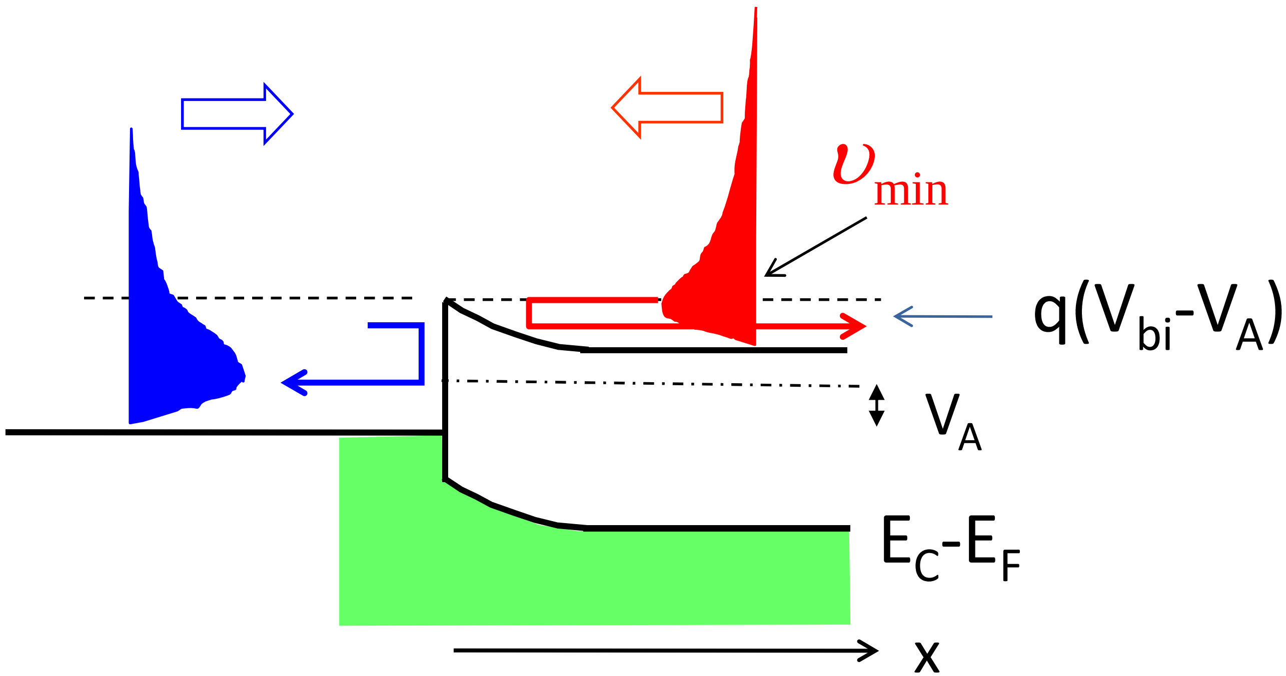
Ref. SDF, Chapter 14

Energy Resolved Thermionic Flux

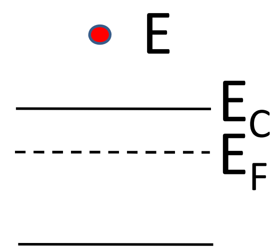
occupation

~ DOS

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



Thermionic Flux from Semi to Metal ..



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

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

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

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

Thermionic Current ...

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

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

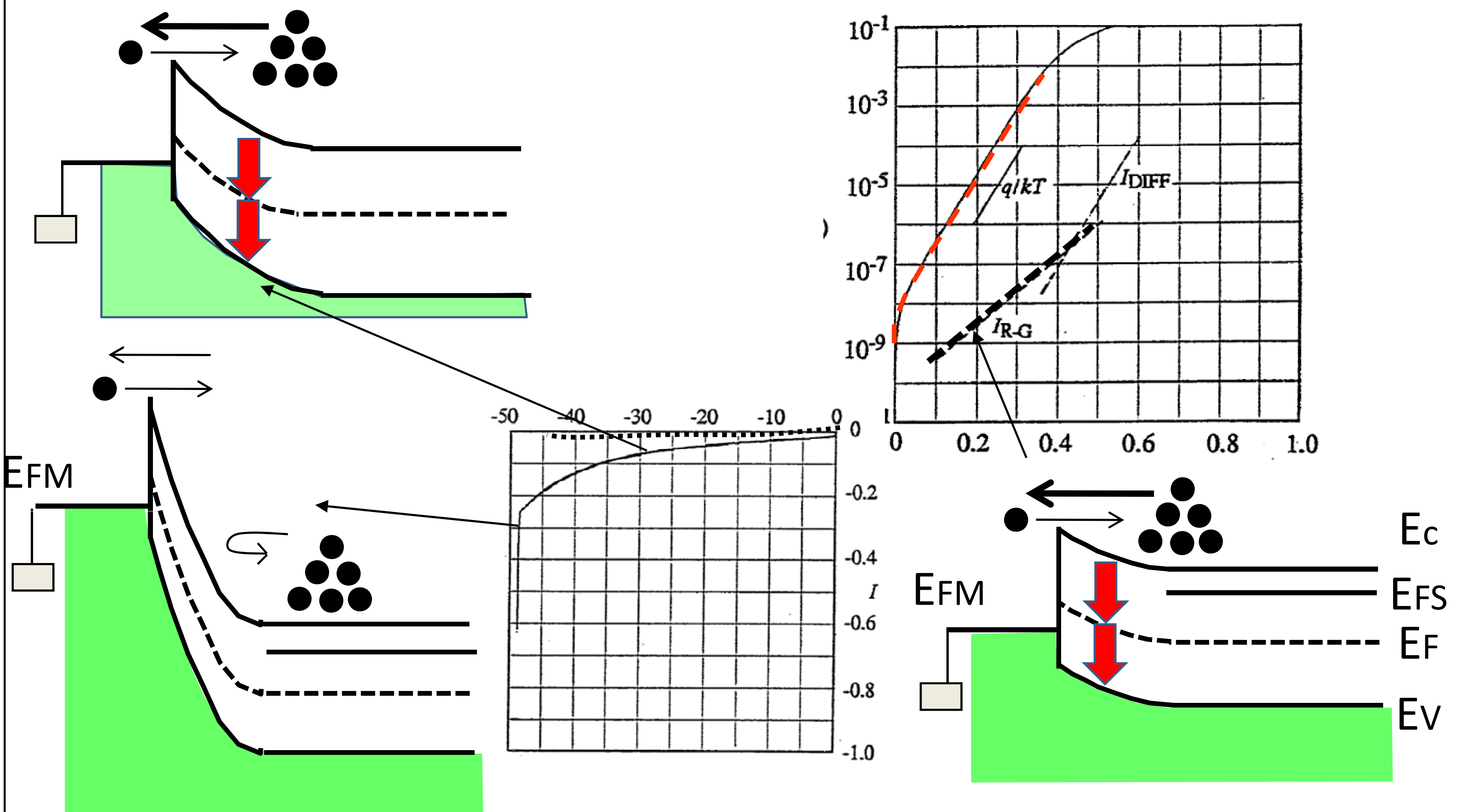
$$\sqrt{\pi} \qquad \sqrt{\pi} \qquad \frac{1}{2} e^{-q(V_{bi} - V_A)\beta}$$

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

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

Compare with p-n junction ... where is the bandgap, doping?

Recombination/Generation/Impact-ionization



SAME technique as in p-n junction except integrate to x_p only

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1) DC Thermionic current (detailed derivation)
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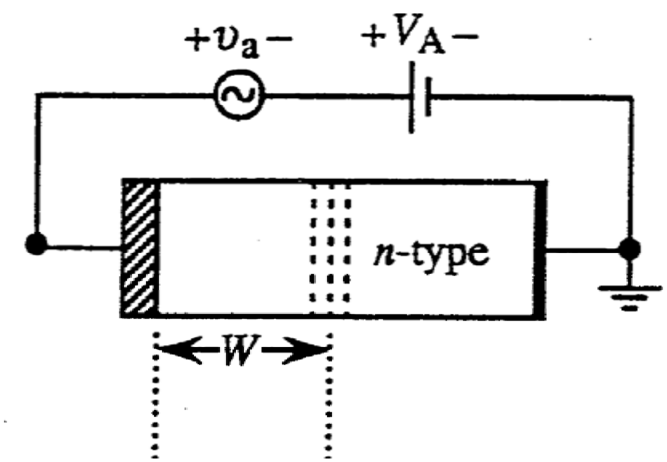
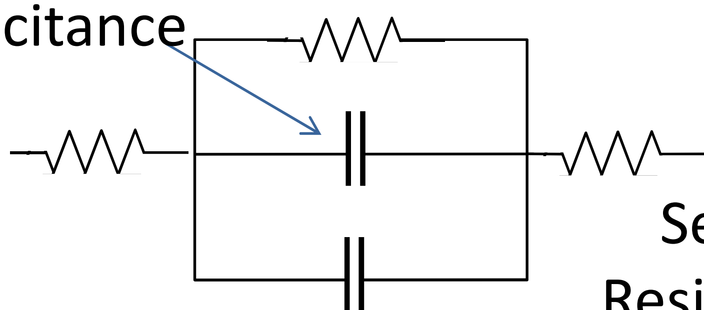
Topic Map

	Equilibrium	DC	Small signal	Large Signal	Circuits
Diode					
Schottky			◆		
BJT/HBT					
MOS					

AC response



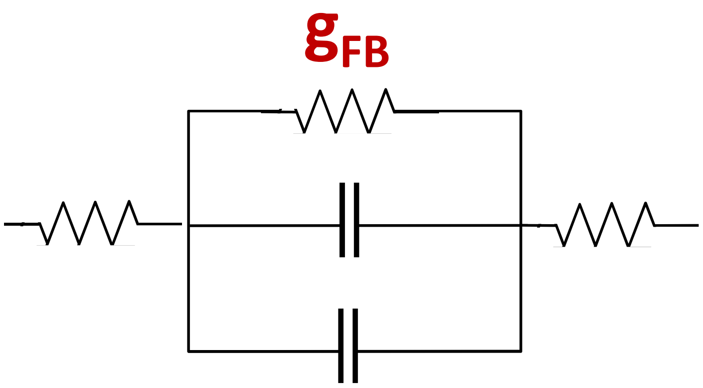
$+v_a-$
$+V_A-$
n-type
W



Conductance
Junction Capacitance
Diffusion Capacitance
Series Resistance

Forward Bias Conductance

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

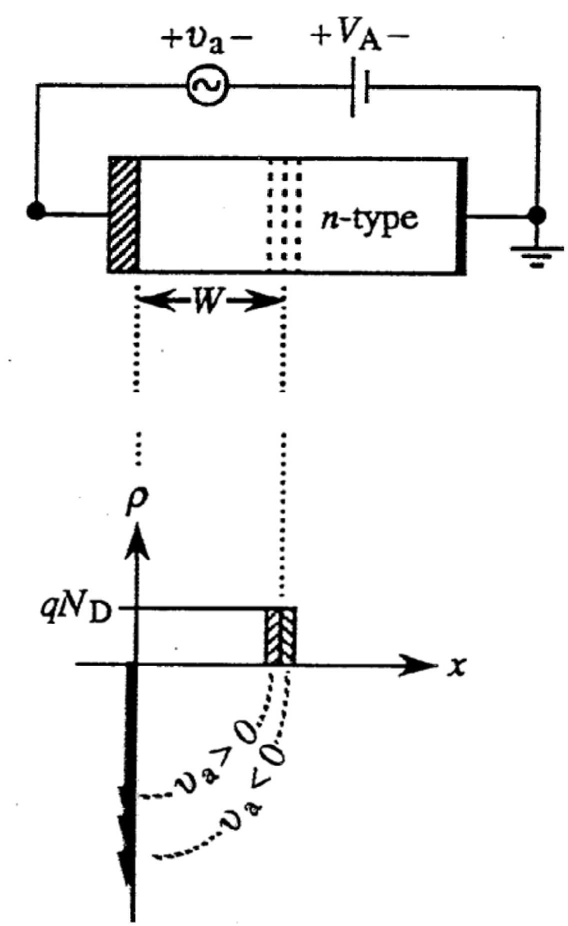


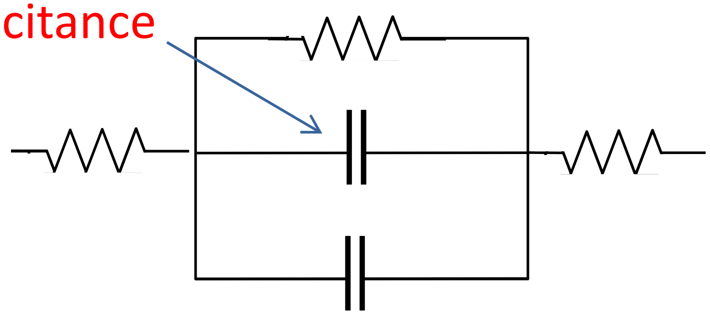
$$\ln\frac{I + I_o}{I_0} = q(V_A - R_S I)\beta / m$$

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

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

Junction Capacitance (Majority Carriers)

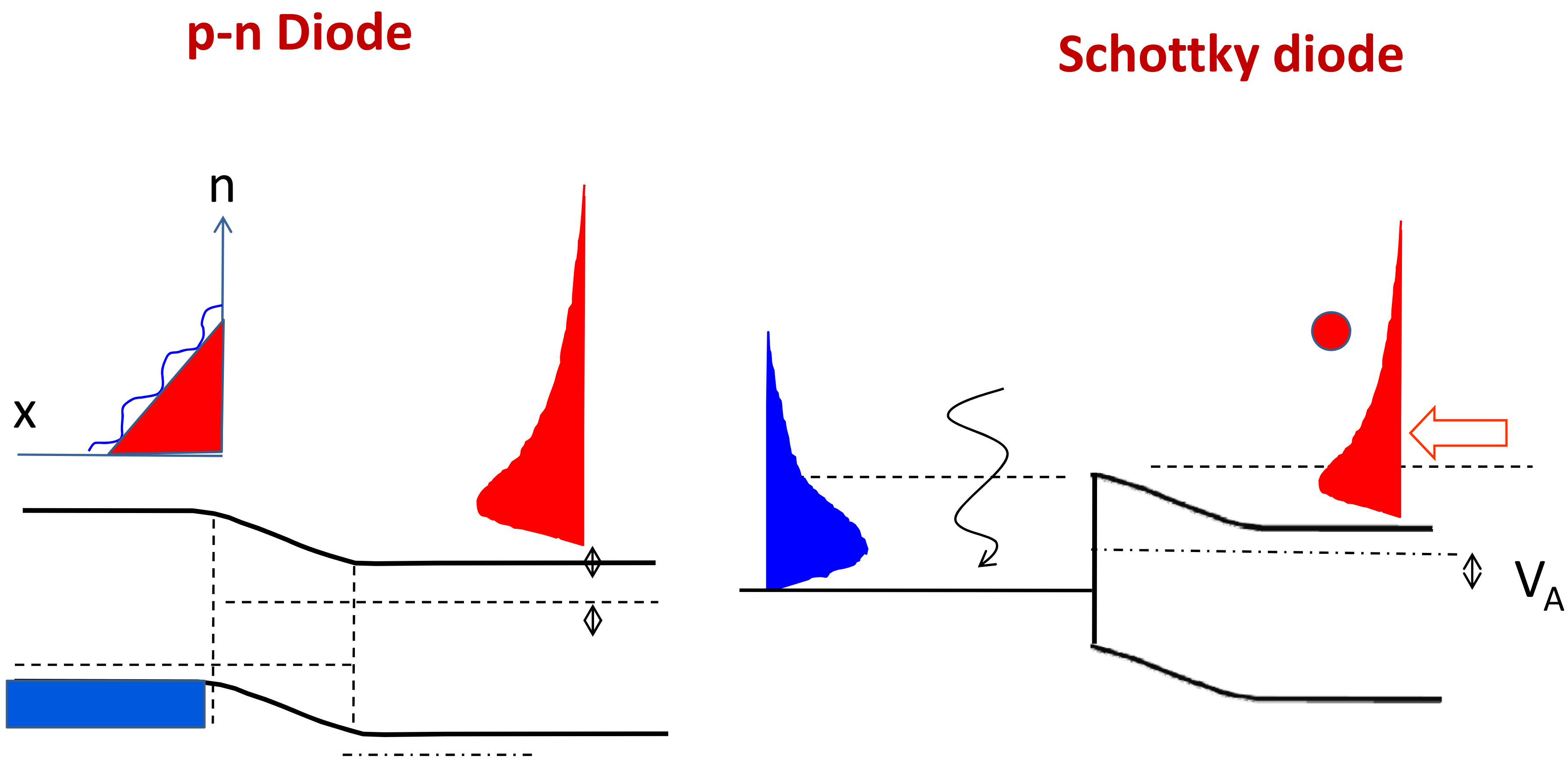




$$C_J = \frac{\kappa_s \varepsilon_0 A}{W}$$

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

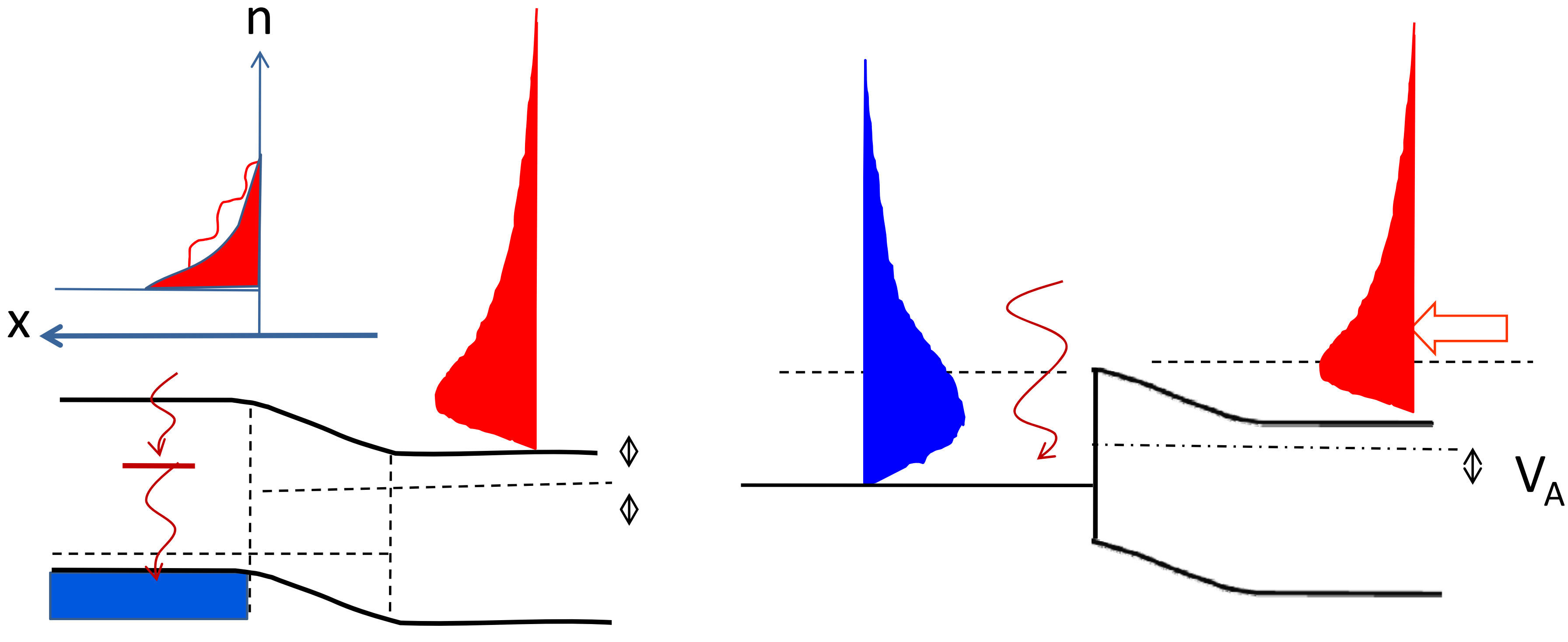
No Diffusion Capacitance in Schottky Diode



No minority carrier transport and therefore no diffusion capacitance ..

Reducing diffusion capacitance in p-n diode

p-n Diode **Schottky diode**



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

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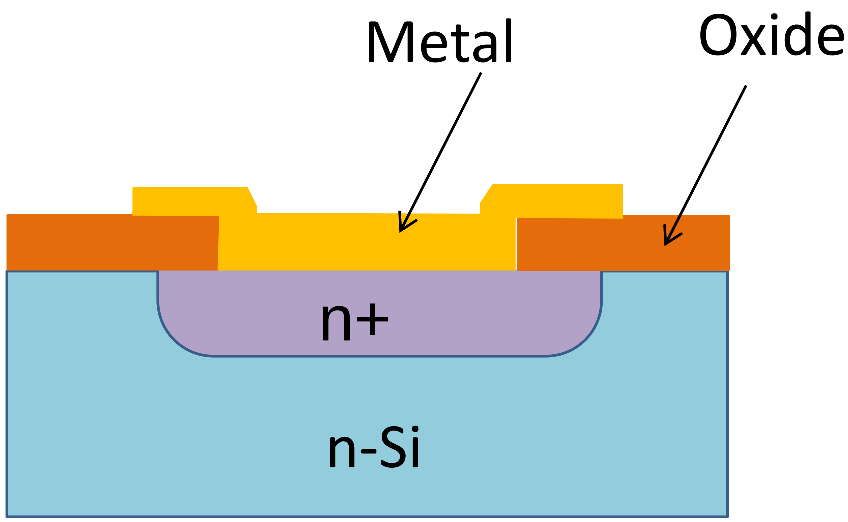
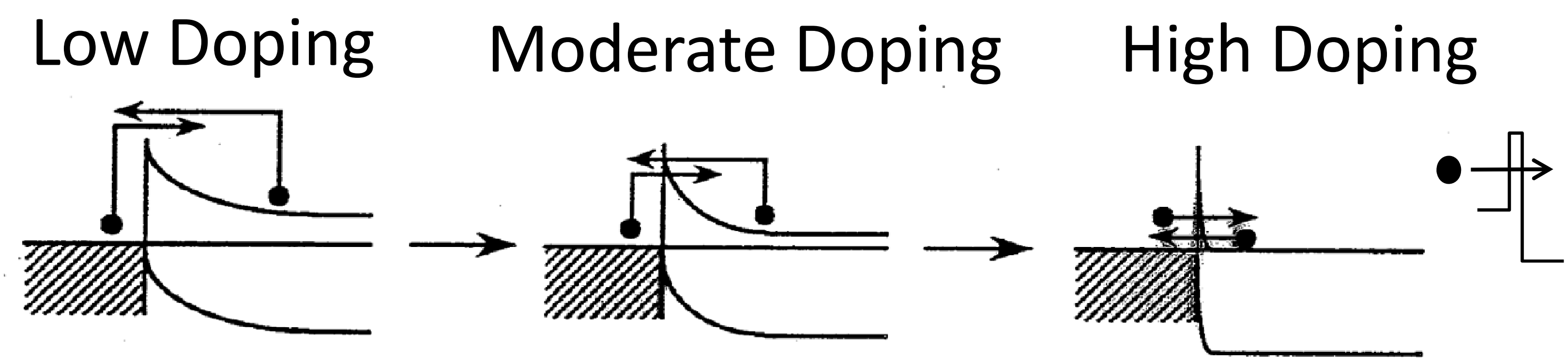
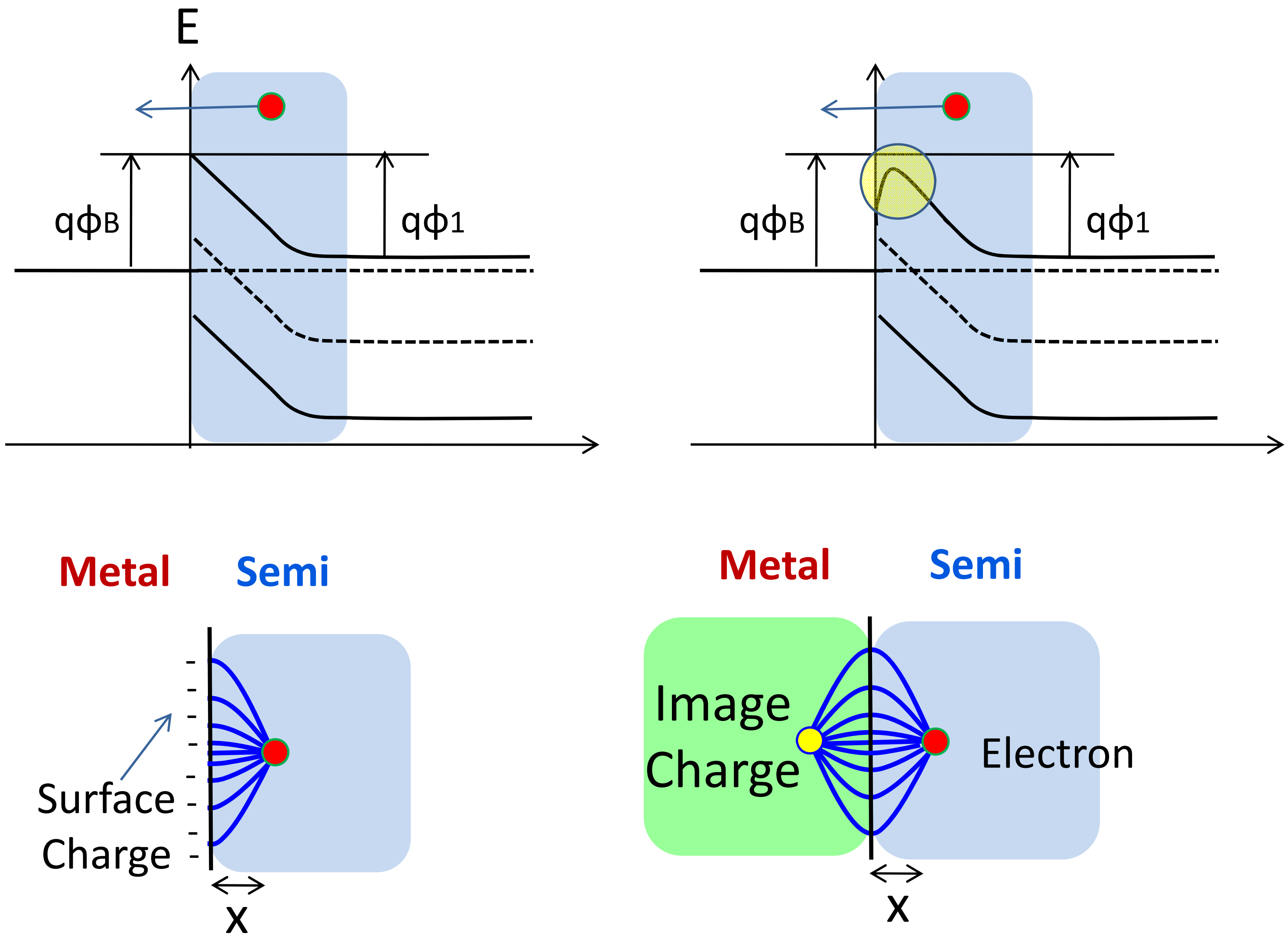
Ohmic Contact vs. Schottky contacts ..



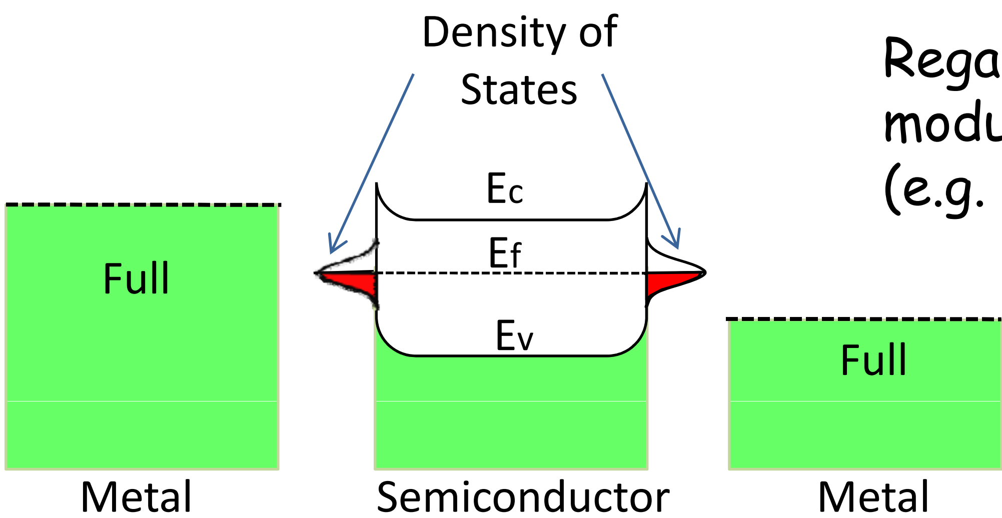


Lowering of Schottky Barrier

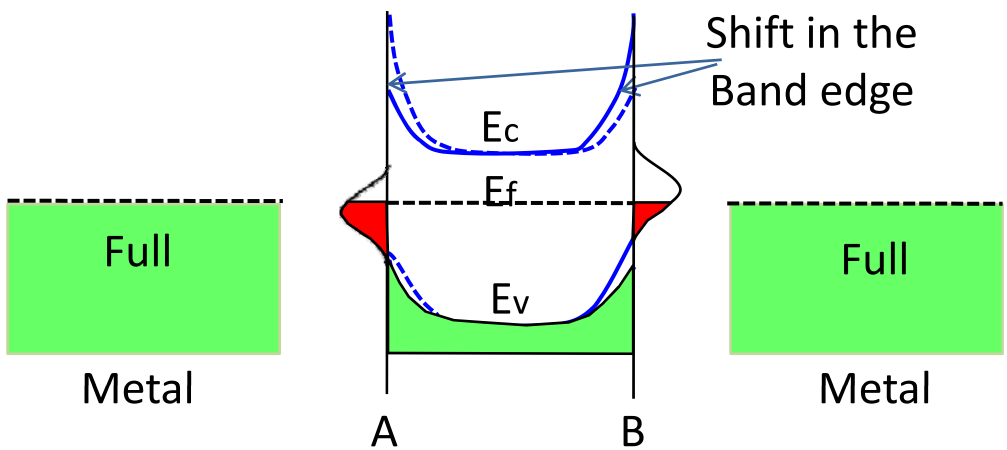


Ref. Sze/Ng., p. 143

Fermi-level Pinning



Regardless the workfunction, no modulation in potential.
(e.g. Modern high-k dielectrics)



Conclusion

1) Schottky diodes have wide range of applications in practical devices.
2) The key distinguishing feature of Schottky diode is that it is a majority carrier device.
3) We use a different technique to calculate the current in a majority carrier device. It is called thermionic emission.