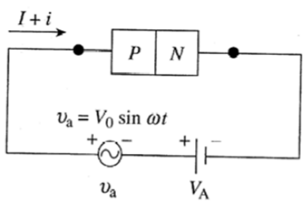
University of Michigan – Shanghai Jiao Tong University Joint Institute
Center of Optics and Optoelectronics

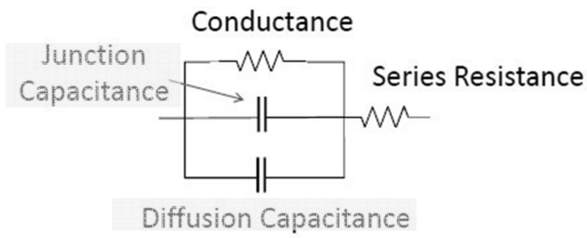
VE 320 – Summer 2012
Introduction to Semiconductor Device

PN Junction Diode AC Response

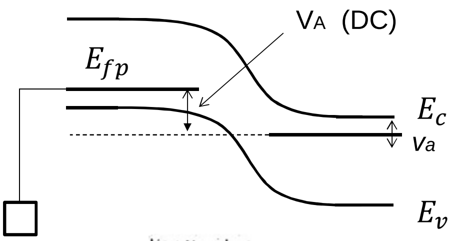
Instructor: Professor Hua Bao

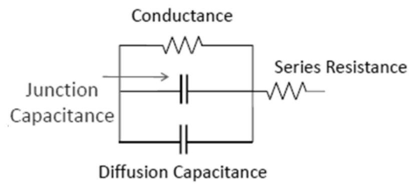
AC Response

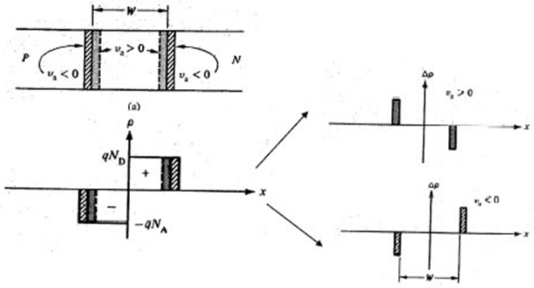




Junction Capacitance





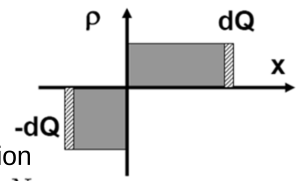


Depletion width and total charge density oscillations in response to an AC signal

Majority Carrier Junction Capacitance

Differential Capacitance (for nonlinear)

$$C = \left|\frac{dQ}{dV}\right|$$



Capacitance associated with depletion region

$$|Q| = qN_A x_p A = qN_D x_n A = qAW\frac{N_A N_D}{N_A + N_D}$$

$$W = \sqrt{\frac{2K_s\varepsilon_0}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)(V_{bi} - V_A)}$$

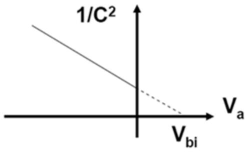
$$\Rightarrow \boxed{C_J = A\sqrt{\frac{K_S\varepsilon_0 q N_A N_D}{2(N_D + N_A)(V_{bi} - V_A)}} = \frac{K_S\varepsilon_0 A}{W}}$$

In the textbook, a different equation is given. Are they the same? why?

Majority Carrier Junction Capacitance

Define $C_{J0} = C_J|_{V_A=0}$

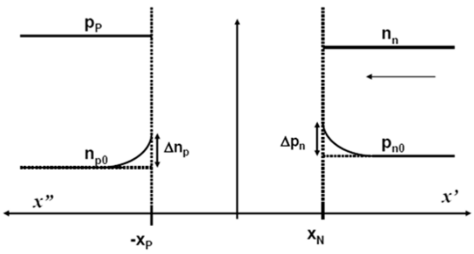
$$C_J = \frac{C_{J0}}{(1-\frac{V_A}{V_{bi}})^{1/2}}$$

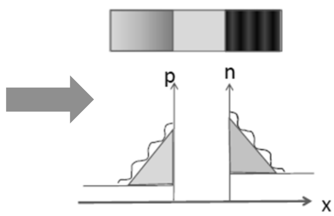


Junction capacitance is proportional to applied voltage. Used as a voltage-dependent capacitor. Built-in voltage can be extracted this way.

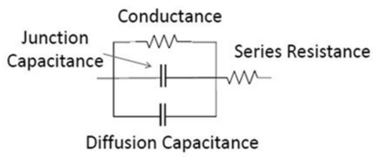
Diffusion Capacitance

Majority carriers respond to the AC signal and create junction capacitance
How about minority carriers?





With AC signal

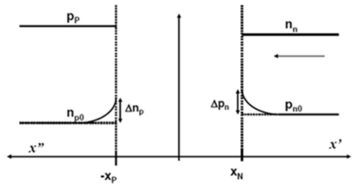


Excess minority carrier density near depletion region edge is the stored charge

Charge Density

$$\Delta n_p(x") = \frac{n_i^2}{N_A}\left(e^{qV_A/kT} - 1\right)e^{-x"/L_N}$$

$$\Delta p_n(x') = \frac{n_i^2}{N_D}\left(e^{eV_A/kT} - 1\right)e^{-x'/L_P}$$



$$Q_p = qA\int_{x_n}^{\infty} \Delta p_n(x)dx = qAp_{n0}L_P(e^{qV_A/kT} - 1)$$

$$Q_n = qA\int_{-\infty}^{-x_p} \Delta n_p(x)dx = qAn_{p0}L_N(e^{qV_A/kT} - 1)$$

Diffusion Capacitance

$$C_D = \frac{dQ_p}{dV} + \frac{dQ_n}{dV}$$

$$\boxed{C_D = \left[Aq^2\frac{n_{p0}L_N + p_{n0}L_P}{kT}\right]\exp\left(\frac{qV_A}{kT}\right)}$$

For p^+-n junction diode

$$C_D = \left(\frac{Aq^2p_{n0}L_P}{kT}\right)\exp\left(\frac{qV_A}{kT}\right)$$

Junction and Diffusion Capacitance

$$C_J = A\sqrt{\frac{K_S\varepsilon_0 q N_A N_D}{2(N_D+N_A)(V_{bi}-V_A)}} = \frac{K_S\varepsilon_0 A}{W}$$

$$C_D = \left[Aq^2\frac{n_{p0}L_N + p_{n0}L_P}{kT}\right]\exp\left(\frac{qV_A}{kT}\right)$$

Under what conditions are each dominant? Why?

Quasi-statical Response

- The above derivations assume that the carriers respond quasi-statically with the a.c. signal.
- At higher frequencies, the carriers cannot move as fast as the rapidly varying signal.

Response time:

Majority Carriers: 10^{-10} s or less for silicon
Minority Carriers: on the order of minority carrier lifetime, eg. 10^{-6} s