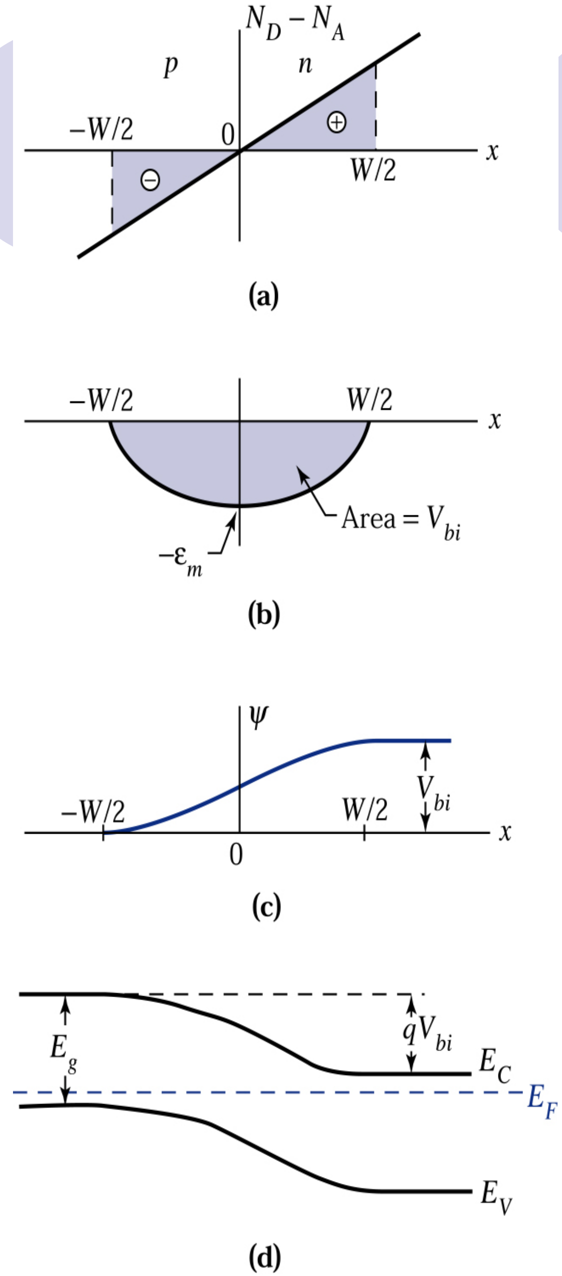
Linearly Graded Junction

- The Poisson equation for the case is

$$\frac{d^2\Psi}{dx^2} = \frac{-q}{\varepsilon_s} ax \qquad \frac{-W}{2} \leq x \leq \frac{W}{2}$$

- Where a is impurity gradient and W is depletion width area.

Figure 4-11.
Linearly graded junction in thermal equilibrium.
(*a*) Impurity distribution.
(*b*) Electric-field distribution.
(*c*) Potential distribution with distance.
(*d*) Energy band diagram.



Linearly graded junction

- Built in Voltage for Linearly Graded Junction

$$V_{bi} = \frac{kT}{q}\ln\left[\frac{(a\frac{W}{2})(a\frac{W}{2})}{n_i^{\,2}}\right] = \frac{2kT}{q}\ln\left[\frac{aW}{2n_i}\right]$$

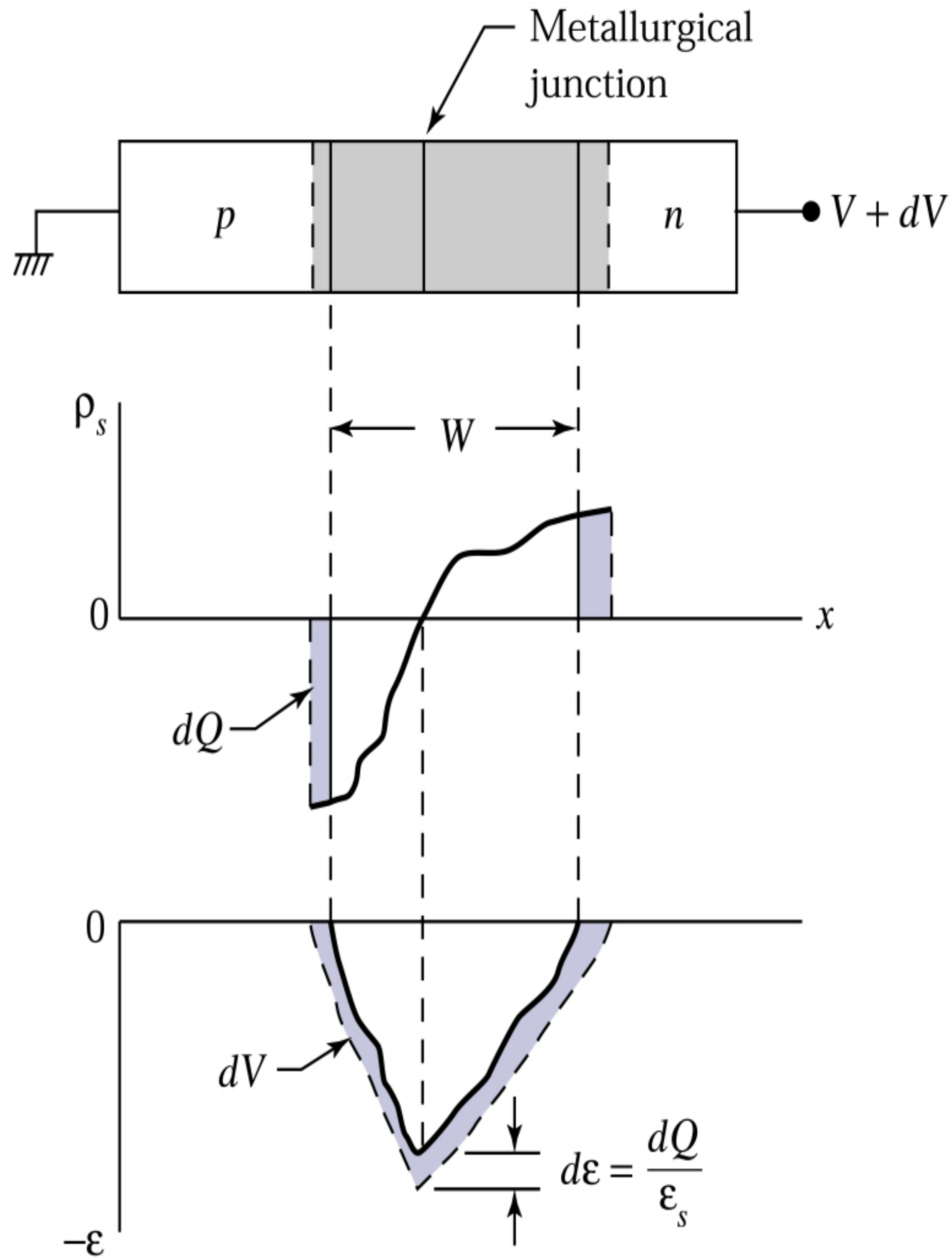
Depletion Capacitance

The depletion layer capacitance per unit area is defined

$$Cj = \frac{dQ}{dV}$$

Where dQ is incremental charge per unit area as for an incremental charge per unit voltage.

Figure 4.13.
(*a*) *p*-*n* junction with an arbitrary impurity profile under reverse bias. (*b*) Change in space charge distribution due to change in applied bias. (*c*) Corresponding change in electric-field distribution.



Depletion Capacitance

- Whenever voltage dv is applied. The charge filed distribution will expand. Figure shows the region bounded by dashed line.
- This increment bring increase in electric field by an amount of $d\varepsilon = \frac{dQ}{\varepsilon_s}$

Capacitance-Voltage Characteristic

- Separation between two plates represents the depletion width. Refer to the figure 13.
- For forward bias large current can flow across the junction corresponding to large number of mobile carrier.
- The incremental change of these mobile carriers with respect to the biasing voltage contributes an additional term called diffusion capacitance.

Capacitance-Voltage Characteristic. Abrupt Junction case

$$Cj = \frac{\varepsilon s}{W} = \sqrt{\frac{q\varepsilon_s N_B}{2(V_{bi} - V)}}$$

Varactor

- Used in many circuit applications.
- Capacitance varies with frequency.
- Concept:
- Reverse biased application depletion capacitance:

$$Cj \propto (Vbi + V_R)^{-n}$$

or

$$Cj \propto (V_R)^{-n}$$

Varactor

- Voltage sensitivity with respect to capacitance is greater in abrupt junction that linear grade.

- This because of n factor which is higher in abrupt as oppose to linear grade.
- From Poisson condition establish the relationship between the depletion region and V_R.

Varactor

- By choosing different value of m we can approximate the relationship between the voltage and junction capacitance

$$W \propto (V_R)^{\frac{1}{m+2}}$$

$$C_j = (V_R)^{\frac{-1}{m+2}}$$

- In RF circuit you can adjust the voltage to control the capacitive value therefore you can control resonant value.

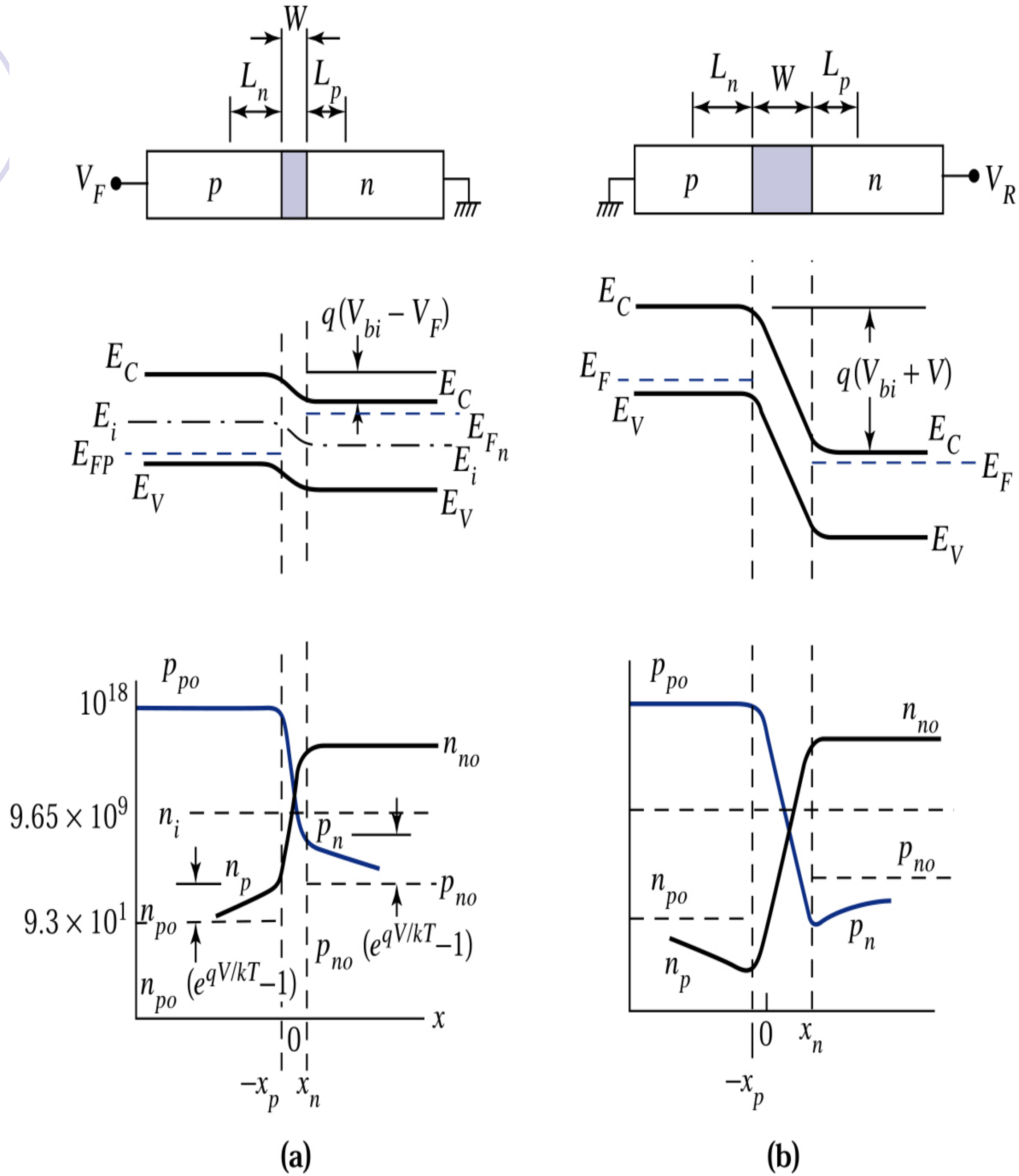
Current Voltage Characteristic

- A voltage applied to a p-n junction will disturb the balance diffussion and drift current.
- Forward bias voltage will increase the diffusion current and decrease the drift current.
- Reverse biased voltage will increase the drift current and reduced the diffusion current.

Ideal characteristic.

- We based on these assumptions:
- Abrupt boundaries ,outside the boundary the semiconductor assume to be neutral.
- Carrier density related by potential different.
- Low density carrier is smaller compare to higher density.
- Electron and hole are constant throughout the depletion region.

Figure 4-16.
Depletion region, energy band diagram and carrier distribution.
(*a*) Forward bias.
(*b*) Reverse bias.



Ideal characteristic.

- Built in Voltage

$$V_{bi} = \frac{kT}{q} \ln \frac{p_{po} n_{no}}{n_i^{\,2}}$$

- The electron density and hole density are related through the electrostatic potential different.

Ideal Characteristic

- Forward bias cause the electrostatic potential different reduced to V_{bi}-V_F.
- Reverse bias electrostatic potential increase V_{bi}+V_R
- $$n_n = n_p e^{q\frac{(Vbi-V)}{kT}}$$
- Where n_n and n_p are non-equilibrium electron densities at the boundary.

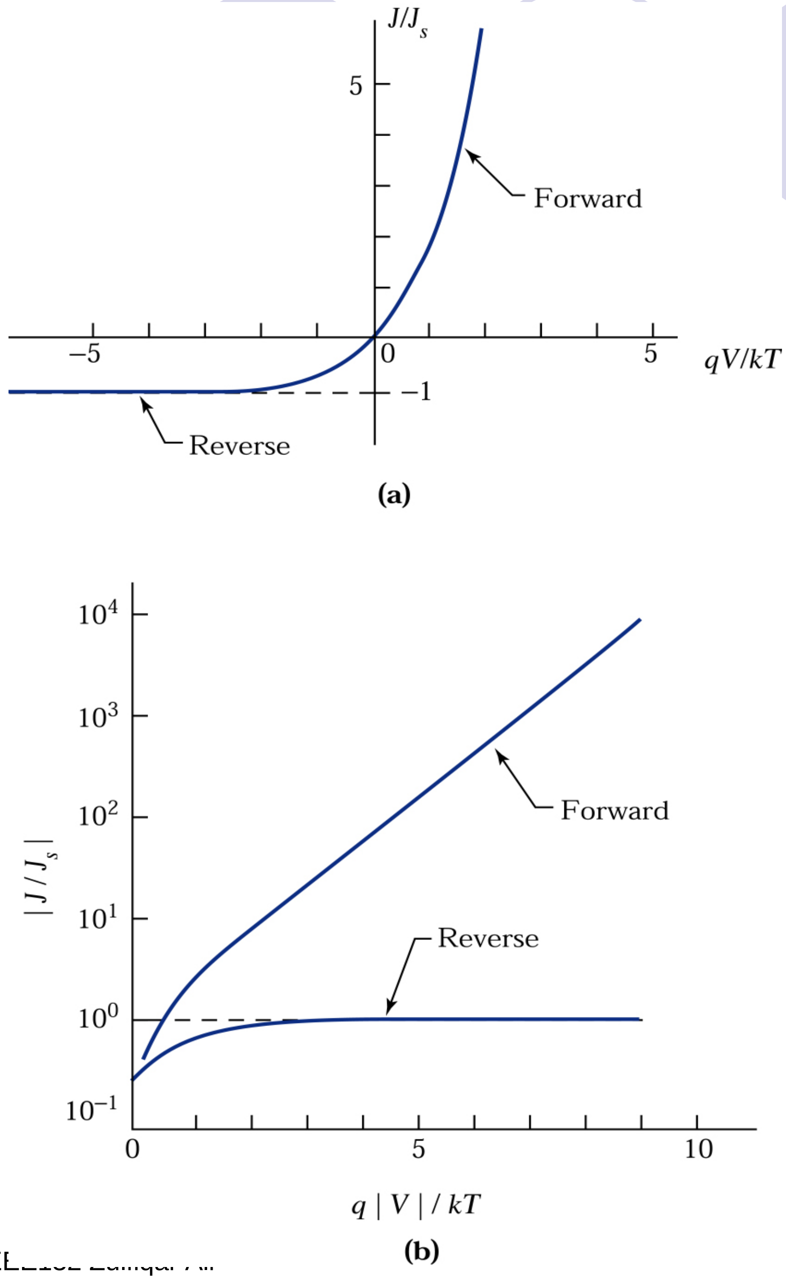
Ideal Characteristic

- Js saturation current Lp and Ln are diffusion length.

$$Js \equiv \frac{qD_p p_{no}}{Lp} + \frac{qD_n n_{po}}{Ln}$$

- The above equation is the ideal diode equation.

Figure 4-18.
Ideal current-voltage characteristics.
(*a*) Cartesian plot.
(*b*) Semilog plot.



Temperature Effect

- Temperature effect has an effect on the device performance.
- In reverse bias as well as forward bias the magnitude of diffusion and generation recombination depend strong on the temperature.

Charge storage and transient behavior

- Under forward bias the electrons are injected into p-type and holes are injected into the n-type.
- Once injected across junction the minority carriers recombine with majority carrier and decay exponentially with distance.
- These lead to current flows and charge storage in the pn junction.

Minority Carrier Storage

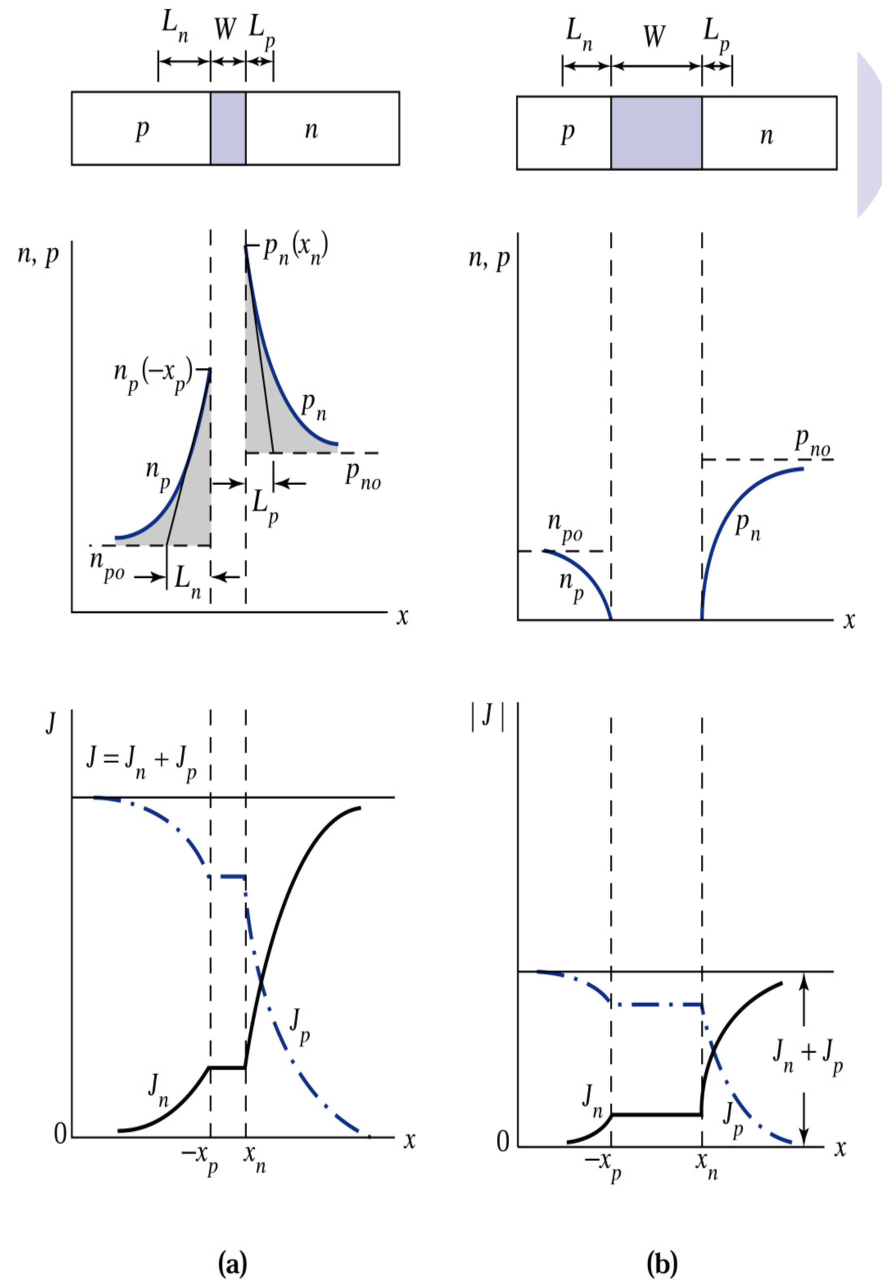
- The charge minority carrier can be found by integrating excess hole in neutral region.

$$Qp = q\int_{xn}^{\infty}(p_n - p_{no})dx$$

$$= qL_p p_{no}(e^{\frac{qV}{kT}-1})$$

$$Qp = \frac{Lp^2}{Dp}Jp(x_n) = \tau pJp(x_n)$$

Figure 4-17.
Injected minority carrier distribution and electron and hole currents. (*a*) Forward bias. (*b*) Reverse bias. The figure illustrates idealized currents. For practical devices, the currents are not constant across the space charge layer.



Diffusion Capacitance

- When the junction is forward biased the is additional significant contribution to the junction capacitance.
- This is called the diffusion capacitance denoted by C_d. A is area of a device.

$$Cd = \frac{Aq^2 Lpp_{no}}{kT} e^{\frac{qV}{kT}}$$

Transient Behavior

- For switching behavior the forward to reverse biased transition must be transient time short.
- Under the forward biased condition the stored minority carrier

$$Qp = \tau p Jp = \tau p \frac{I_F}{A}$$

$$toff \cong \frac{QpA}{I_{Rave}} = \tau p \left(\frac{I_F}{I_{Rave}} \right)$$

Junction Breakdown

- When large reverse voltage is applied to p-n junction, the junction breaks down and conducts a very large current.
- The important breakdown mechanism:
- Tunneling process and avalance mechanism.

Tunneling Effect

- High electric field is applied in reverse direction valence electron make transition from valence band to conduction band.
- Only occurs if the electric field is high about 10^6V/cm

Avalance multiplication

- This occurs under the reverse bias condition.
- The thermally generated electron gain kinetic energy from the electric field.
- If the field is sufficiently high it can gain enough kinetic energy to break the bond creating electron hole pair.
- The newly created electron hole pair requires energy thus create more electron hole pair and this is called the avalance multiplication.