

1) pn-junction diode temperature dependence

$$V_D = V_T \ln\left(\frac{i_D}{I_S} + 1\right) = \frac{kT}{q} \ln\left(\frac{i_D}{I_S} + 1\right)$$

$$V_D = f(T), \quad I_S = f(T)$$

$$\frac{dV_D}{dT} = \frac{V_D - V_{G0} - 3V_T}{T}$$

V_D = voltage across the diode

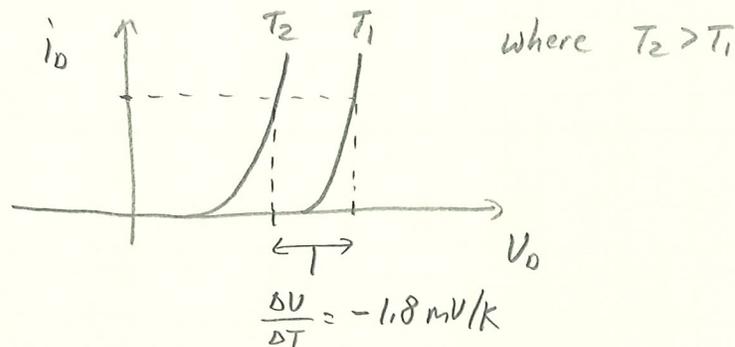
$$V_{G0} = \text{Si bandgap energy at } 0K = \frac{E_G}{q}$$

V_T = thermal voltage

For: $V_D = 0.65V$, $E_G = 1.2eV$ and $V_T = 0.025V$ { room temp }, $T = 300K$

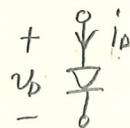
$$\therefore \frac{dV_D}{dT} = -1.82 \text{ mV/K}$$

What this means: at close to room temperature:



2) Diodes under reverse bias

$$V_R = \text{reverse bias voltage} = -V_D$$



Φ_j = junction potential across the pn junction space charge region

When the diode is in reverse bias: V_R adds with Φ_j

$$\text{so that } V_j = \Phi_j + V_R$$

where V_R is now the voltage ^{across the} space charge region (or depletion region)

Result: the width of the space charge region increases:

$$\text{When } V_D = V_R = 0: w_{d0} = \sqrt{\frac{2 \epsilon_s}{q} \left(\frac{1}{N_A} + \frac{1}{N_D} \right) \phi_j}$$

when $V_R > 0$ {reverse bias}:

$$w_d = \sqrt{\frac{2 \epsilon_s}{q} \left(\frac{1}{N_A} + \frac{1}{N_D} \right) (\phi_j + V_R)} = w_{d0} \sqrt{1 + \frac{V_R}{\phi_j}}$$

As the depletion region increases, I_s , the saturation current, also increases:

$$I_s = I_{s0} \sqrt{1 + \frac{V_R}{\phi_j}}$$

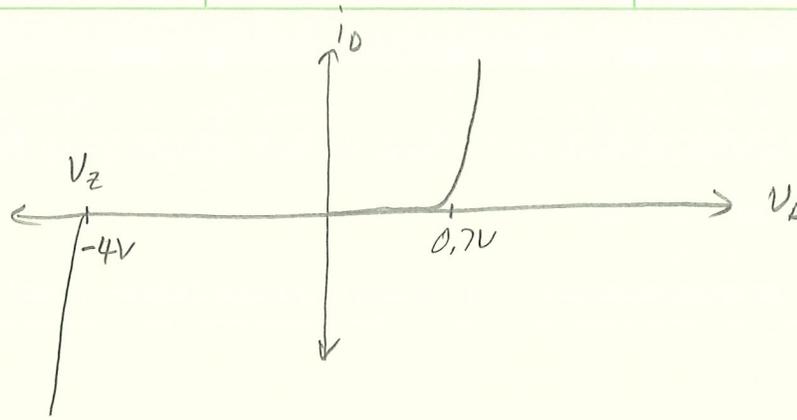
Note: under forward bias: the depletion layer width changes very little, $\therefore I_s = I_{s0}$ for forward bias

a. Reverse Breakdown

if V_R is increased enough, the diode will enter the "breakdown region", where current flow will rapidly increase for further increase in V_R

The voltage where breakdown occurs is called the breakdown voltage, V_Z .

Ex:



Typically: $2V \leq V_Z \leq 200V$

V_Z is primarily determined by doping level

2 Breakdown Mechanisms: avalanche breakdown and Zener breakdown

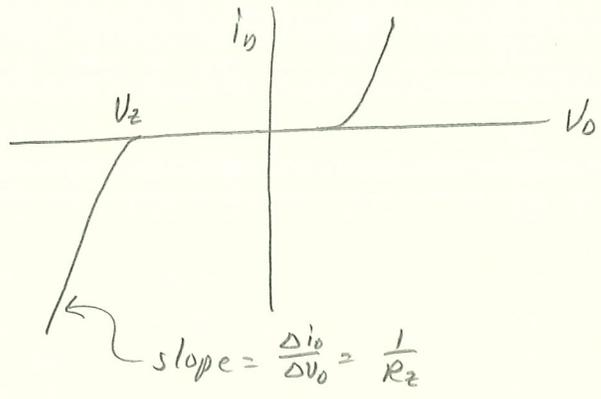
① Avalanche Breakdown

→ as the depletion layer width increases with increasing V_R , free carriers are accelerated through the SCR by V_j . If they gain enough KE, they can strike an atom and break a covalent bond → creating a new $e^-/hole$ pair. It also accelerates and repeats the process → chain reaction resulting in significant current flow

② Zener Breakdown

→ only in heavily doped diodes → results in a narrow depletion band
 → V_R cause charge carriers to tunnel through the conduction and valence bands, resulting in significant current flow

Circuit model for diode in reverse breakdown



schematic symbol for the zener diode:

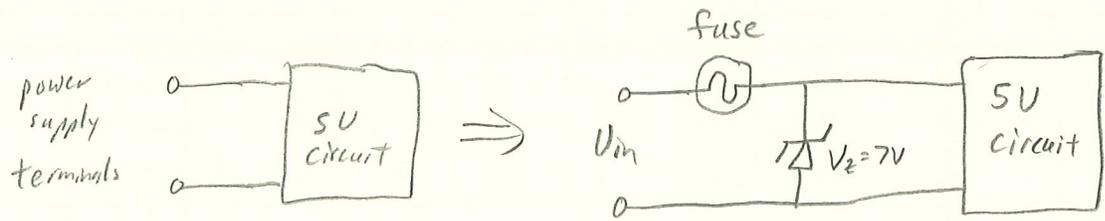


reverse breakdown model



Zener Diodes → diodes made to take advantage of the Zener breakdown

Zener diode application



too high an input voltage will destroy the circuit

For $V_{in} \geq 7V \rightarrow$ zener diode turns on shorts to 7V. ∴ blowing the fuse

3) Capacitance in pn junction diodes

→ the pn junction depletion region contains charge

∴ it has a capacitance associated with it: at $V_0 = 0 \rightarrow C = C_{j0}$

In reverse bias $\rightarrow V_R \uparrow$: depletion region width \uparrow

∴ in reverse bias:
$$C_j = \frac{C_{j0} A}{\sqrt{1 + \frac{V_R}{\phi_j}}}$$

↓
"zero-bias junction capacitance"
$$C_{j0} = \frac{\epsilon_s}{w_{d0}}$$

∴ in reverse bias \rightarrow the diode has a voltage controlled capacitance

↓ when utilized, the symbol



↓

called a variable capacitance diode or varactor

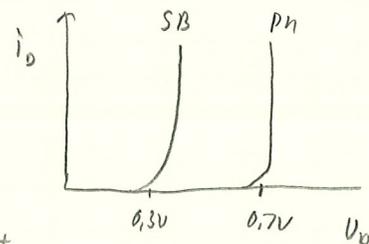
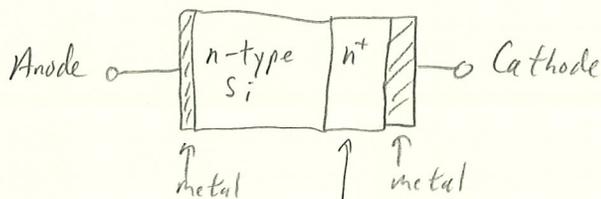
In forward bias: $V_0 > 0$: the diode also has a

capacitance:
$$C_D \approx \frac{i_0 \tau_T}{V_T}$$

τ_T is the transit time: $10^{-5} \text{ s} \leq \tau_T \leq 10^{-6} \text{ s}$

4) Schottky Barrier Diode

→ can make a diode with just n-type Si and a metal (ohmic) contact



symbol



SB has lower turn-on voltage than pn