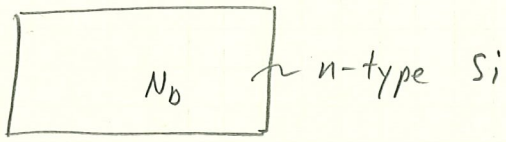
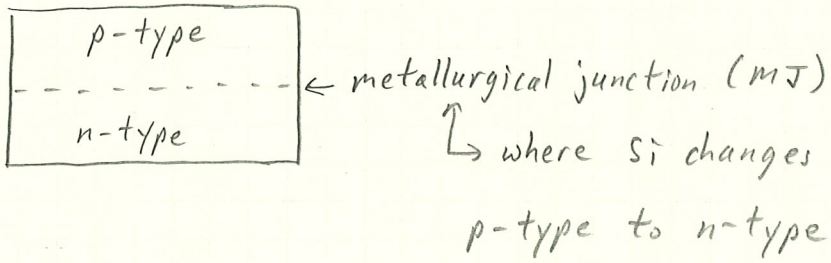
1. The pn junction diode

- start with an n-type Si wafer with donor impurity doping: N_D

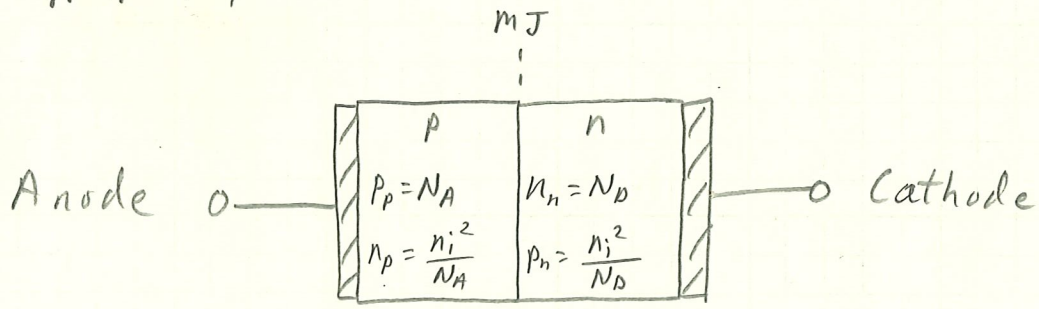


- selectively dope the wafer with acceptor impurity atoms where $N_A > N_D$ → makes substrate portion p-type

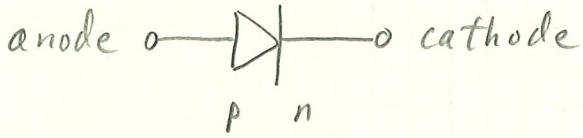
∴



- appropriately metallize both sides to make electrical contacts



schematic symbol



Typical charge carrier concentrations:

p-type side	n-type side
$p_p = 10^{17}$ holes/cm^3	$p_n = 10^4$ holes/cm^3
$n_p = 10^3$ e^-'s/cm^3	$n_n = 10^{16}$ e^-'s/cm^3

→ large concentration of holes on p-type side of MJ
→ large " " e^-'s " n-type " " "

∴ some mobile holes will diffuse across the MJ to the n-type side
" " e^-'s " " " " " " " p-type side

∴ on p-type side of MJ → immobile negative charged acceptor atoms remain

∴ on n-type side of MJ → immobile ionized donor atoms with a localized positive charge remain

→ This results in the development of a <u>Space Charge Region</u> (SCR), depleted of mobile charge carriers around the MJ → also called a <u>Depletion Region</u> or <u>Depletion Layer</u>

→ The SCR results in an electric field that limits additional charge carrier diffusion across the MJ
↳ "Electric Field" ⟶ results in a built-in potential across the pn junction ; $\phi_j = -\int E(x)\,dx$, $[\phi_j] = V$

$$= V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

W_{d0} = depletion-layer width (in x-direction)

$$= (x_n + x_p)$$

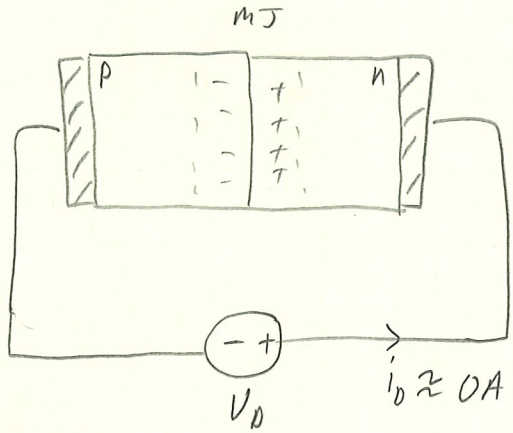
$$\sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)\phi_j}$$

$[W_{d0}] = m$

The SCR E-field results in drift currents in opposite direction to diffusion currents, so that they balance out

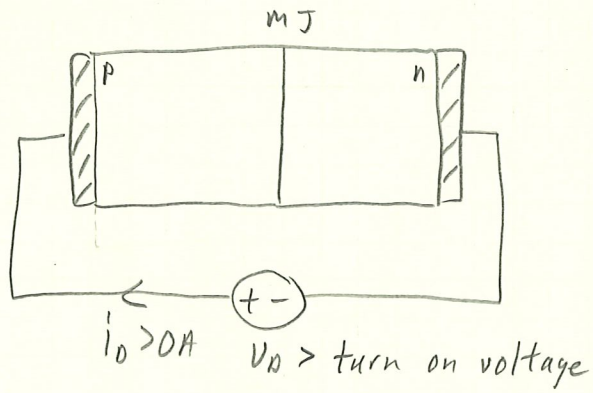
a. Applying a voltage across the pn junction

① <u>Reverse Bias Operation</u>



- Applied negative voltage increases the potential barrier to a net of charge carriers moving across the MJ: $i_D \approx 0A$

② <u>Forward Bias Operation</u>



- a positive applied voltage reduces the potential barrier

$$i_D = I_s\left[e^{\left(\frac{V_D}{nV_T}\right)} - 1\right]$$

where: I_s = Reverse Saturation Current: typically $10^{-18} A \leq I_s \leq 10^{-9} A$

n = nonideality factor: typically $n = 1$ to 1.1

V_T = thermal voltage $= \frac{kT}{q}$

<u>Note</u>: if $T\uparrow$, $V_D\uparrow$ for same i_D

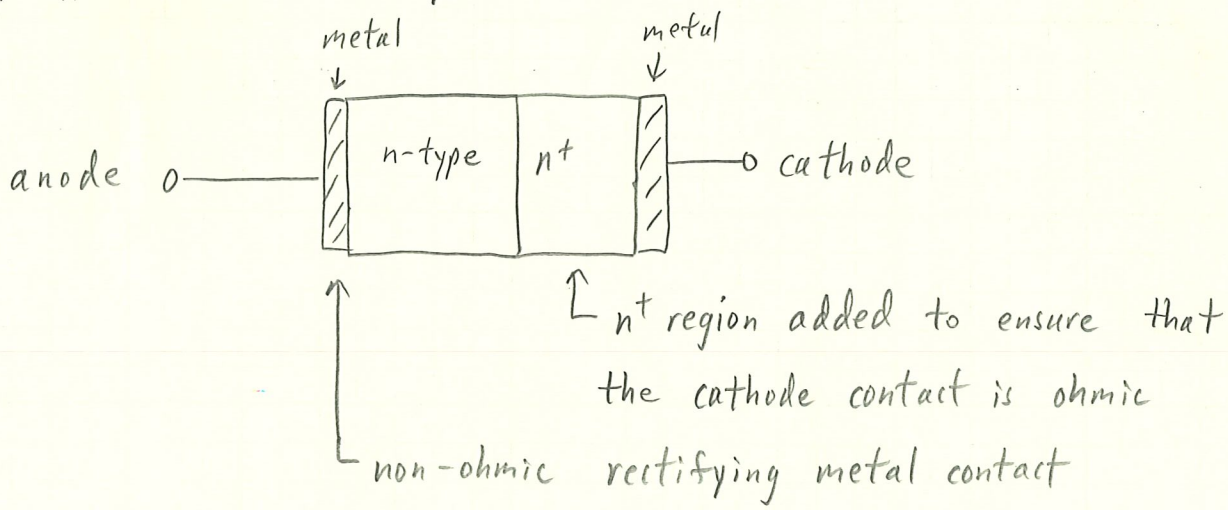
b. Reverse Breakdown

① Avalanche Breakdown → impact-ionization process: depletion layer increases under reverse bias until E field is strong enough to accelerate e^-'s to a velocity fast enough to break covalent bonds upon impact → impact-ionization, ∴ creating electron-hole pairs

② Zener Breakdown → reverse bias induced carrier tunneling directly between conduction and valence energy bands in heavily doped diodes

2. Schottky Barrier Diode

p-type Si side is replaced with a metal conductor: "contact"



→ has a much lower turn on voltage than a p-n junction.

3. The amazing PN junction

① rectifier
② photovoltaic device
③ LED
④ TEC - solid state heat pump or power generator: Peltier effect
⑤ Photo diode → camera
⑥ temp sensor
⑦ 2 pn junctions → BJT transistor