Photovoltaics

Tuesday, February 13, 2024 3:57 PM

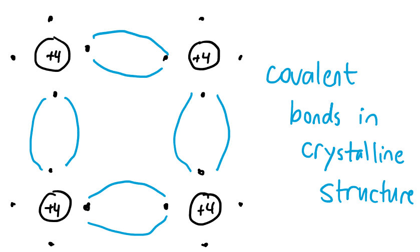
Photovoltaic Material / Device

- A material/device that can convert energy in photons of light into electrical energy

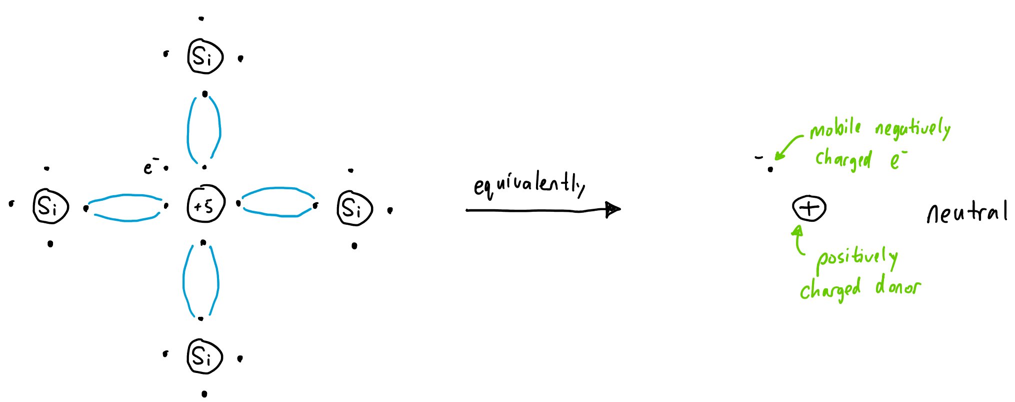
- PV commercialization has been impacted by cost in the past. But now installed cost \$1/W (for utility-scaled solar PV)

- Shockley-Queisser Limit (1961)
  - Theoretical limit of power efficiency for single p-n junction ~33% (can do better with more layers)

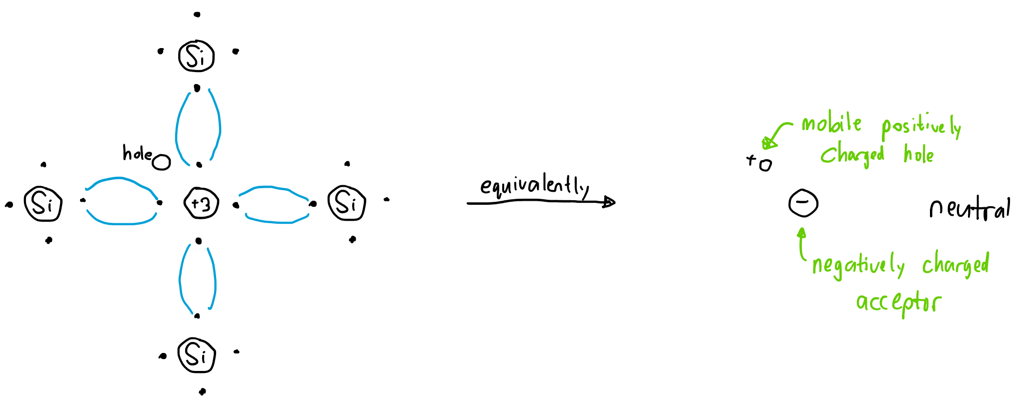
- PV devices use semiconductors, mainly Si
  - Si atom has 14 protons, 14 electrons (of which 4 are valence electrons)
  - A common representation:



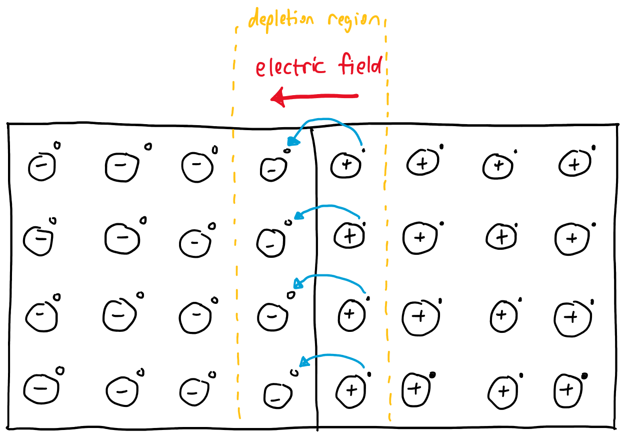
  - n-type material: doped with a pentavalent donor (e.g. P, As)



- p-type material: doped with trivalent acceptors (e.g. B, Ga)

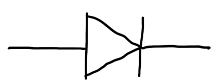


- Create p-n junction w/ p-type and n-type materials



p-type material
- majority carrier: holes
- minority carrier: e^-

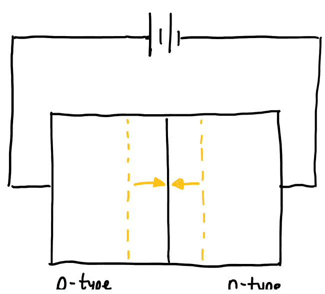
n-type material
- majority carrier: e^-
- minority carrier: holes



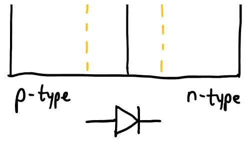
- e^-/hole recombinations in the depletion region
- Create internal electric field
- electric field stops further diffusion
  - ↳ Stop flow of majority carriers across junction

- <u>2 types of currents in p-n junction</u>

1) diffusion current
   - majority carrier (e^-) on n-side cross into p-side
   - In forward bias, barrier is lower and more e^- diffuse



- In forward bias, barrier is lower and more e^- diffuse



We don't want this (forward)
see illuminated junction

2) drift current

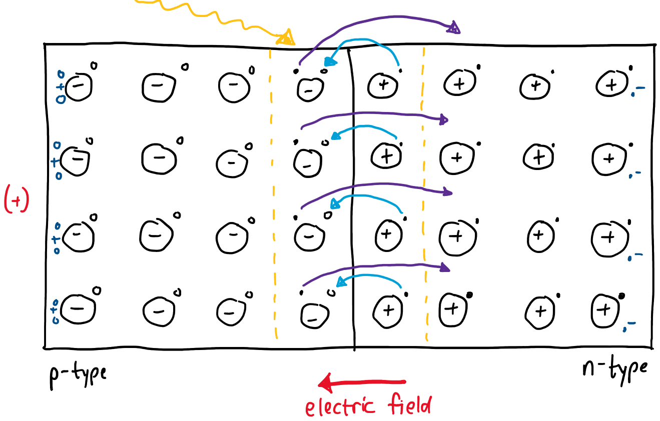
- minority carriers (e^-) on p-side "wander" into transition region
- small because there are few minority carriers

GOAL: optical excitation of EHPs near the junction

☆ Want drift current

- Illuminated Junctions
  - Forward bias is not an option (want PV to generate)
  - Need optical excitation near the junction to provide drift/"generation" current

① photon $h\nu > E_{gap} = 1.12\,eV$ (bandgap energy for Si)

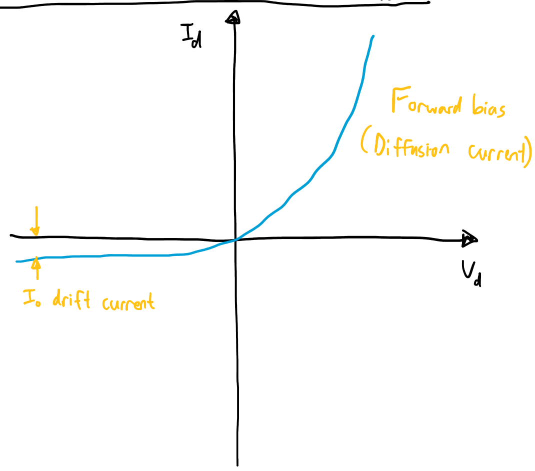


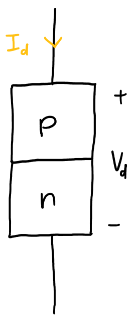
② e^- swept across due to internal electric field → drift current

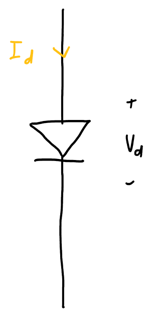
③ accumulate e^- on n-side, holes on p-side

④ Drift current creates voltage

- p-n Junction Circuit Model







From circuits course:

$$I_d = I_o\left(e^{qV_d/kT} - 1\right)$$

diode current ← I_d

reverse saturation current [A] ← I_o

→ Temperature of junction [K]

→ Boltzmann constant $= 1.381 \times 10^{-23}$ [J/K] diode current

reverse saturation current [A]

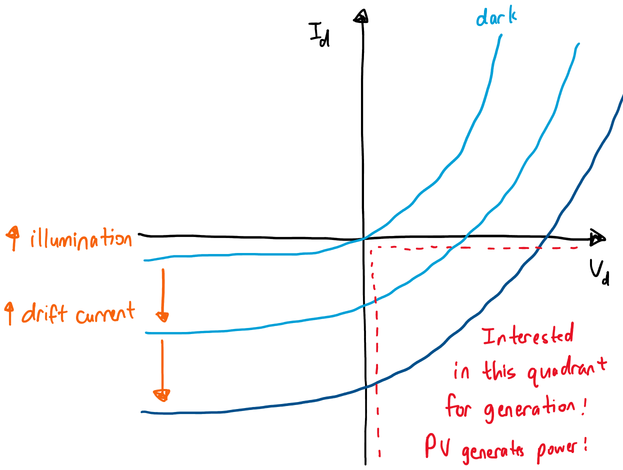
electron charge = 1.602×10^{-19} [C]

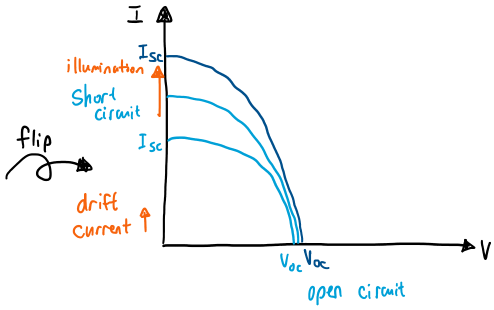
Temperature of junction [K]

Boltzmann constant = 1.381×10^{-23} [J/K]

voltage across diode [V]

- Increase "drift" or "generation" current by optical excitation





$I_{sc} \propto$ solar intensity