Today

Monday, April 6, 2020 4:42 PM

Exam 2 - April 9th (Thursday)

- I will send out at midnight US Central Time
- Have 24 hours to complete
- It should take you less than 2
- Submit through Gradescope
- Don't panic

<u>Today</u>

- Basic semiconductor physics
- Band gap energy
- The PN Junction
- Exam 2 Topics

Basic Semiconductor Physics

- PV devices use semiconductor materials to convert sunlight into electricity
- Technology is similar to solid-state technologies used to make transistors, diodes, and all other devices that we use today.
- Most PV generation devices are made out of pure crystalline silicon.

13	14	15 Pnicto-gens	16 Chalco-gens	17 Halogens	18 Noble gases
					Helium 2 He 4.0026
Boron 5 B 10.81	Carbon 6 C 12.011	Nitrogen 7 N 14.007	Oxygen 8 O 15.999	Fluorine 9 F 18.998	Neon 10 Ne 20.180
Alumin-ium 13 Al 26.982	Silicon 14 Si 28.085	Phos-phorus 15 P 30.974	Sulfur 16 S 32.06	Chlorine 17 Cl 35.45	Argon 18 Ar 39.95
Gallium 31 Ga 69.723	Germa-nium 32 Ge 72.630	Arsenic 33 As 74.922	Selenium 34 Se 78.971	Bromine 35 Br 79.904	Krypton 36 Kr 83.798
Indium 49 In 114.82	Tin 50 Sn 118.71	Antimony 51 Sb 121.76	Tellurium 52 Te 127.60	Iodine 53 I 126.90	Xenon 54 Xe 131.29

Fourth group of the periodic table

- Includes Germanium, which is also widely used in devices

Band Gap Energy

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Band Gap Energy

- At absolute zero temperature, silicon is a perfect electrical insulator. There are no electrons free to roam around as there are in metals
- As temperature rises, some electrons are given enough energy to free themselves from their nuclei, making them available to flow as current.
- The warmer they get, the more electrons are available to carry current, so conductivity increases.
- Silicon's conductivity at normal temperature is very low => it is referred to as a semiconductor.

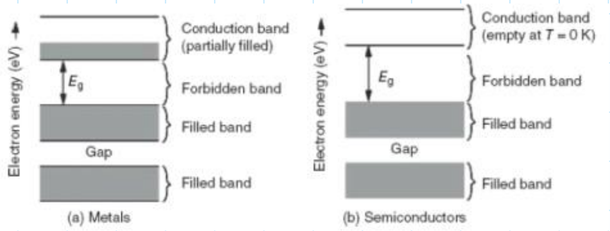
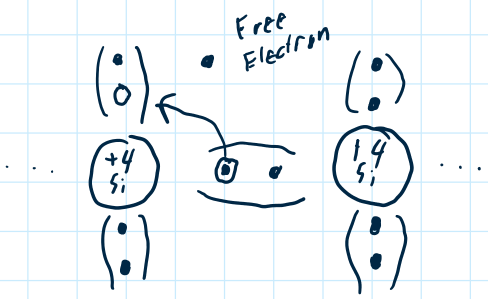


Fig 5.4

We can use an energy band diagram (Fig 5.4).

- Electrons have energies that must fit within certain allowable energy bands
- At room temperature, only about 1 out of 10^{10} electrons in silicon exists in the conduction band
- The gaps between the allowable energy bands are called forbidden bands. The most important one is the band between the last filled band and the conduction band.
- The energy than an electron must acquire to jump across the forbidden band is called the **band-gap energy**.
- The units for band-gap energy are usually eV (electron-volts), where one eV is the energy that an electron acquires when its voltage is increased by 1 V (1 eV = 1.6 x 10^{-19} J).
- The band-gap energy for silicon is 1.12 eV
  - The energy required to free an electron from its own nucleus.
  - In the case of a PV, this energy comes from the sun: photons of electromagnetic energy



Negatively charged electron moves in conduction band
↳ holes can move too as valence electrons move to fill empty holes

Photons with enough energy will create a hole-electron pair

Photons with enough energy will create a hole-electron pair

Photons can be characterized by their wave length, frequency and energy:

$C = \lambda \, \nu$

- ν → frequency (Hz)
- λ → wave length (m)
- C → speed of light

$E = h \cdot \nu = \frac{hc}{\lambda}$

E: Energy of photon (J)
h: Plank's constant (6.626×10^{-34} J·S)
c: 3×10^8 m/s

Example (5.1 in book)

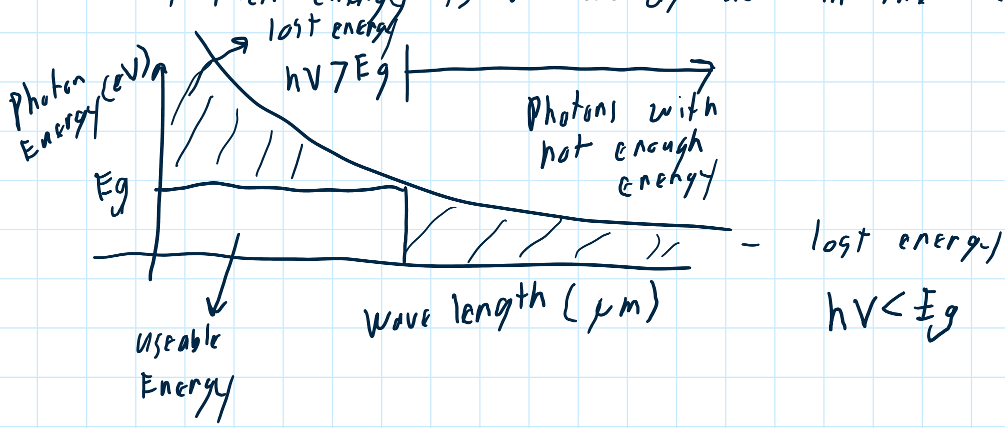
Photons to create Hole-Electron Pairs in Silicon

- what maximum wave length can a photon have to create hole-electron pairs in silicon?
  what min frequency is that?
  Si Band gap = 1.12 eV, 1eV = 1.6×10^{-19} J

$\lambda \leq \frac{h \cdot c}{E_g} = 1.11 \mu m$ $E = \frac{hc}{\lambda}$ → any larger will result in lower E

$\nu \geq \frac{c}{\lambda} = 2.7 \times 10^{44}$ Hz

For photons with $\lambda > 1.11 \mu m$, they cannot create electron-hole pairs
⇒ their energy is wasted as heat in the cell



For photons with $\lambda < 1.11 \mu m$, the additional energy above E_g is also wasted

The P-N Junction

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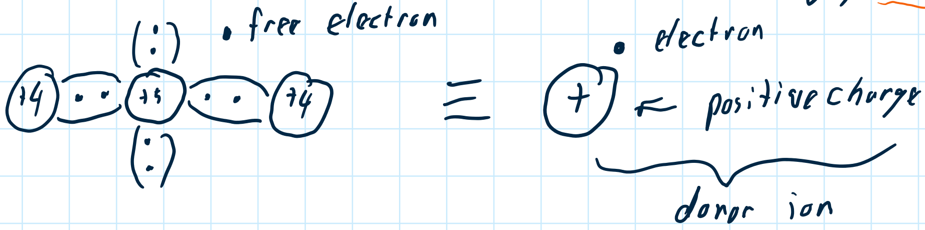
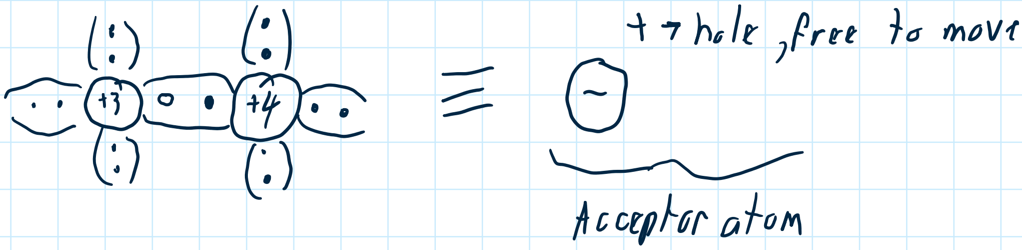
N-type material
- Dope silicon with a pentavalent material (e.g., phosphorus)



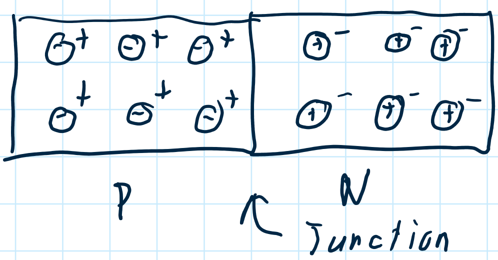
- Fixed immobile positive charge
- Freely roaming negative charge ⇒ n-type material

P-type material
- Dope silicon with a trivalent element (eg, boron)

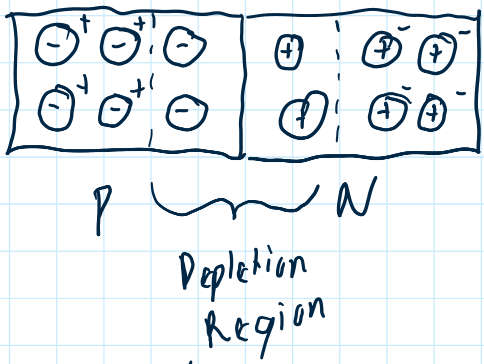


Fixed negative charge
Mobile hole (positive charge) → P-type

P-N Junction



Electrons cross junction through diffusion, fill holes in P-type material



⇒ after, there are not electrons or holes free to move in the vicinity of the junction

E electric field (positive ch...

Regi...

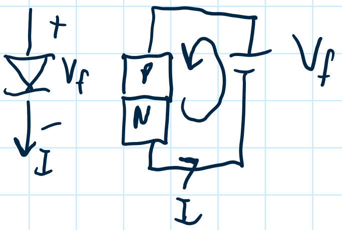
$\leftarrow$ E electric field (positive charges move in direction of arrow)

No bias => No current

Reverse Bias => strengthens E field, no current

Forward Bias => weakens E field, allows electrons to flow across depletion region

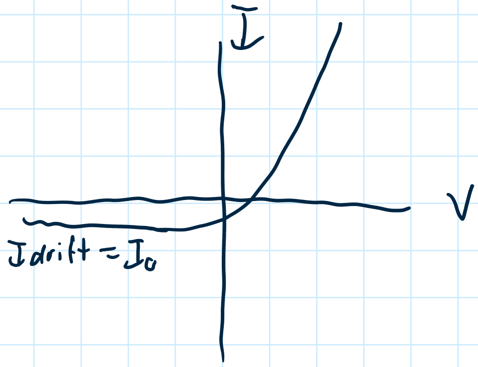
This is a diode



$\leftarrow$ We need to provide a Voltage with this polarity for current to flow?

Is this what we want? ... Nope

P-N Junction Model



$$J = J_o(e^{qV/kT} - 1)$$

Recall:

Forward Bias: $V > 0$

$e^{qV/kT} >> 1$

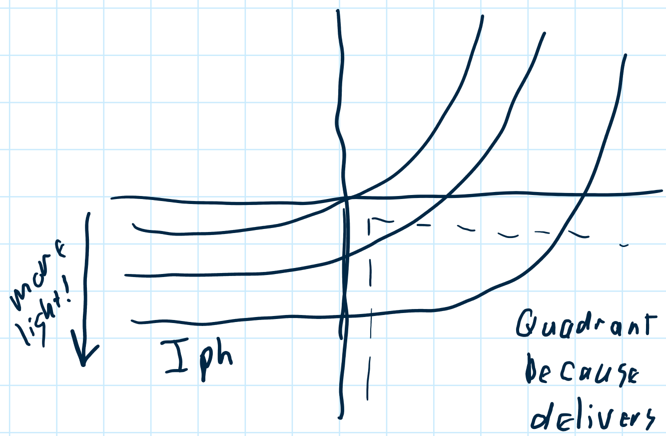
$\Rightarrow I \sim J_o e^{qV/kT}$

(diffussion current)

=> sensitive to forward voltage

Let's look at this drift current:

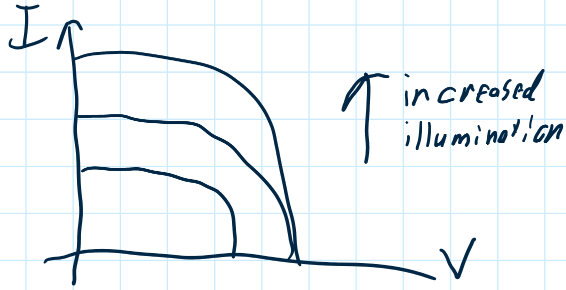
- caused by minority carriers (e^- on p-side)
  - ↳ typically small because there are few minority carriers
  - ↳ However, optical excitation creates electron-hole pairs
    - ↳ drift current increases!



Quadrant of interest because PV cell delivers power

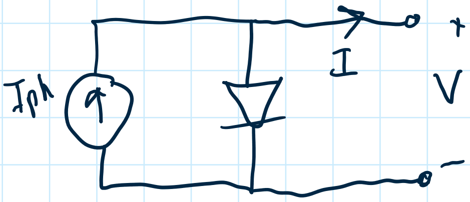
Now, lets flip this around

=>



Useful ckt. model

Ideal single diode PV cell Model



$$I = I_{ph} - I_o\left(e^{qV/kT} - 1\right)$$

→ conventional P-N diode
↳ diffusion
thermally created drift current
voltage bias

I_{ph} ↓

Generation current (drift) } ∝ amount of sunlight, temp, area ...

Exam 2 Review

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Types of WECs

Bernoulli's Eqn

Betz Efficiency

Statistics (PDF, CDF)

Rayleigh statistics

Economics

- Cash Flows
- IRR
- PVF, CRF
- Life cycle costs
- Inflation

TSR

Ideal Power Curve