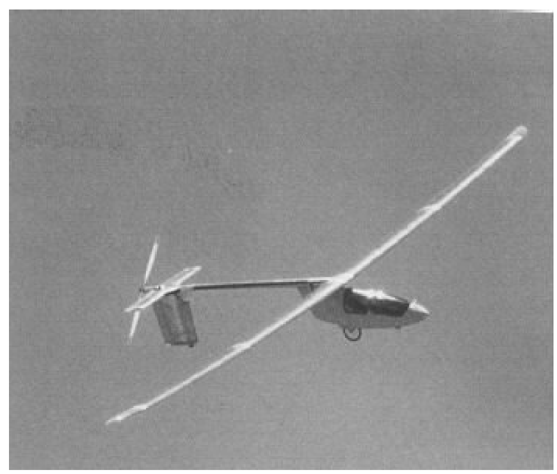
SOLAR CELLS

LECTURE 1

Prof. John David



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Lecture notes :
Either at http://www.shef.ac.uk/webct/ or http://hercules.shef.ac.uk/eee/teach/resources/MEC316/MEC316.html

ENG306 SOLAR CELLS

OUTLINE SYLLABUS

- **Lecture 1**
  - Direct generation of electricity from solar energy, crystalline semiconductors, carrier generation and recombination, photogeneration of carriers
- **Lecture 2**
  - Junction diode, I-V characteristics, photodiode, solar cell realisation, equivalent circuit of cell
- **Lecture 3**
  - Open- and short-circuit conditions, I-V characteristics of cell, power delivered, fill-factor
- **Lecture 4**
  - Array of cells, domestic application, alternative technologies

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- **Books**

  Electronic Engineering Semiconductors and Devices J.Allison, Mcgraw-Hill

  Physics of Semiconductor Devices, S.M.Sze, Wiley

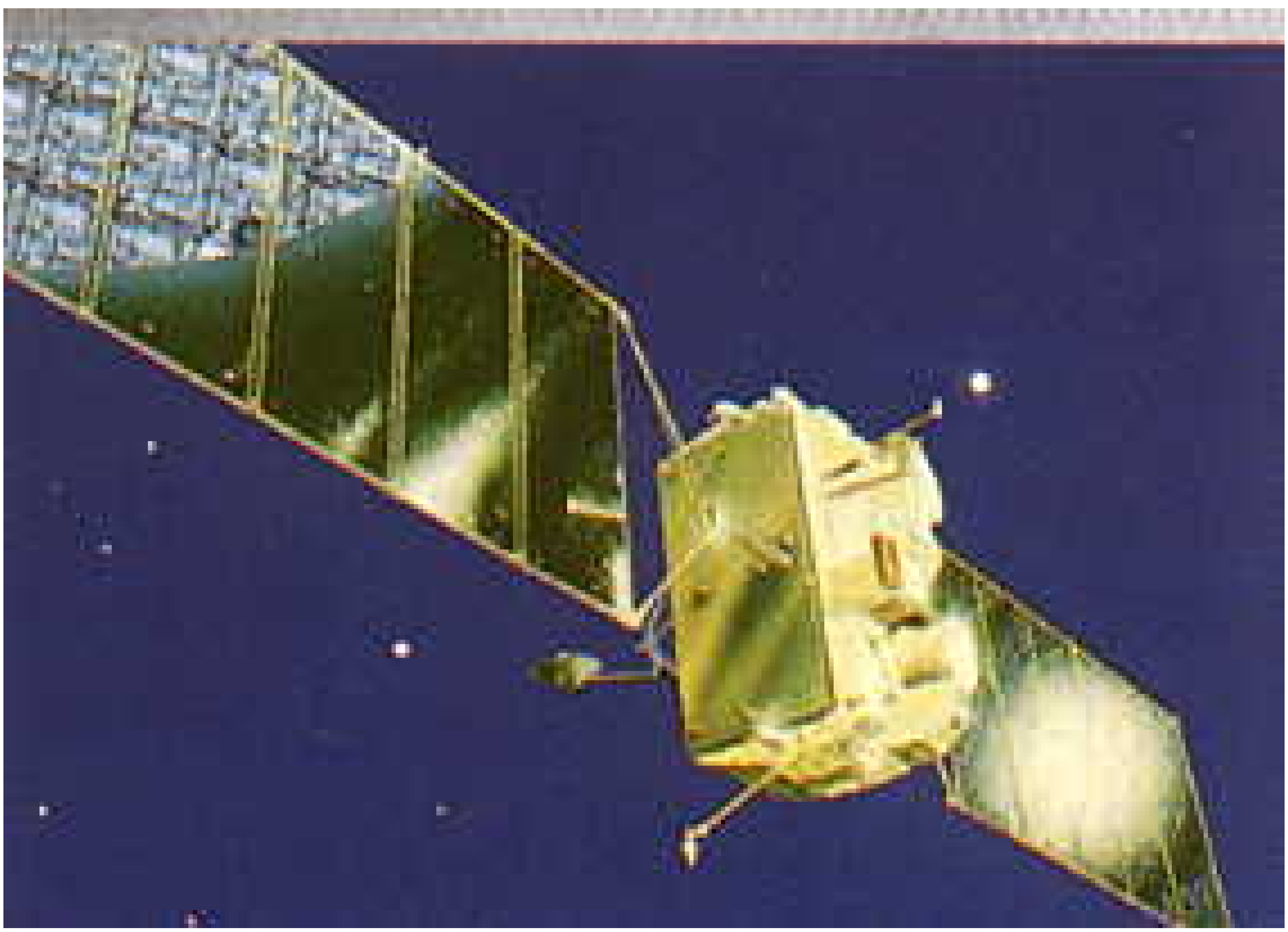
  Solid State Electronic Devices, B.G.Streetman, Prentice Hall

THE PHOTO-ELECTRIC EFFECT

Sunlight can directly generate electricity using the PHOTO-ELECTRIC EFFECT.

Devices using this effect are called solar cells.

Solar cells are common in space satellites



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Sunlight can directly generate electricity using the PHOTO-ELECTRIC EFFECT.

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Solar cells are common in space satellites and in remote earth locations such as radio beacons and TV repeaters

This picture shows a solar powered illuminated warning buoy

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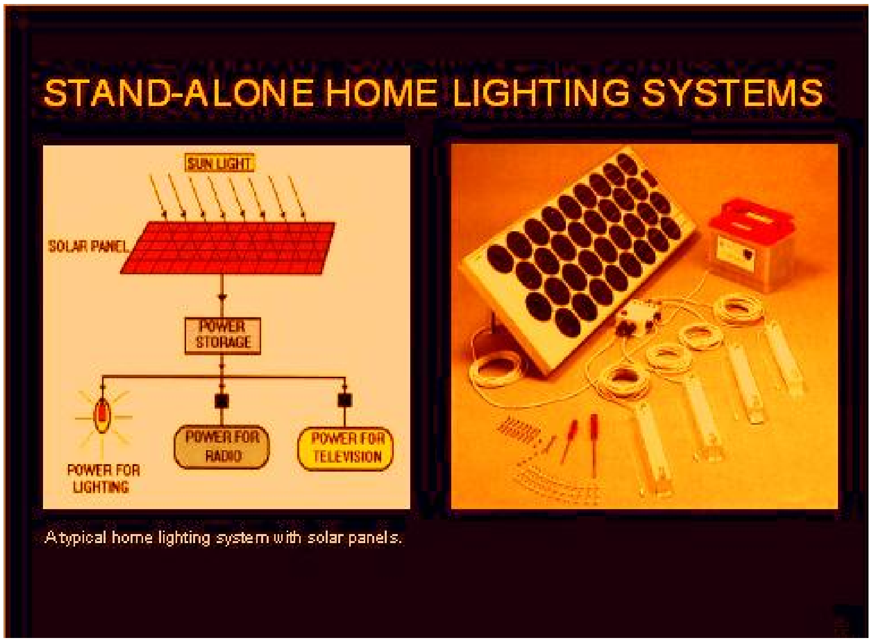
This solar cell array powers a water pumping station in Burkina Faso

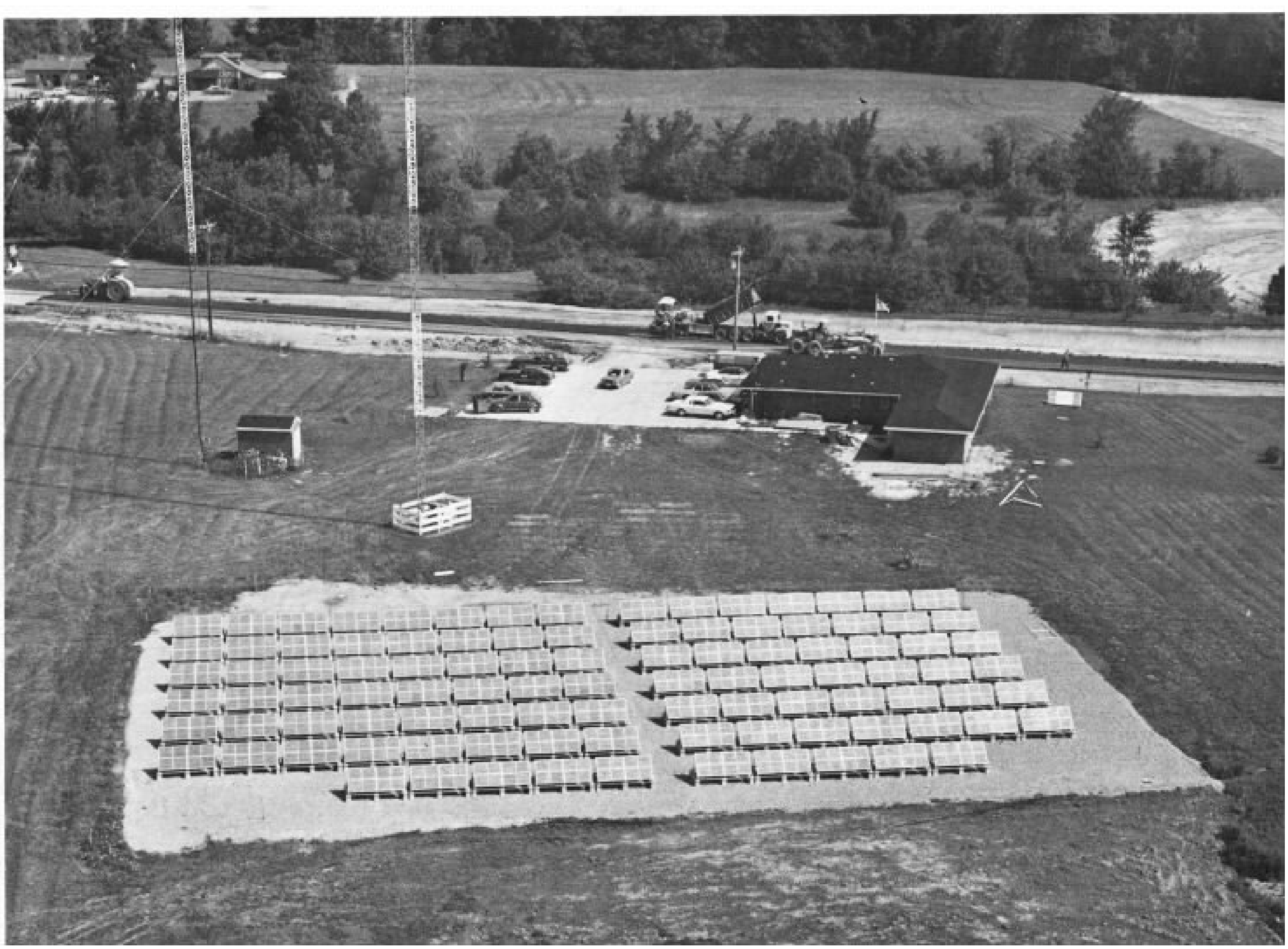
THE PHOTO-ELECTRIC EFFECT

These 50W solar panels are used in rural areas in Sri Lanka to provide power for limited lighting, radio and television



THE PHOTO-ELECTRIC EFFECT

This 15kW solar cell array covers 1/3 acre and contains 33,600 solar cells. The array powers a commercial radio station in Ohio which only transmits during daytime. The system was installed in 1979.



THE PHOTO-ELECTRIC EFFECT

Even in the UK solar cells have found applications in supplying power for equipment such as parking meters and parking ticket machines in both rural and urban environments

DOMESTIC APPLICATION OF SOLAR CELLS

The ultimate goal of photovoltaic technology is to provide low cost efficient solar power for widespread domestic application. Solar cells with efficiencies near the theoretical limit have been developed, but COST is the over-riding factor in limiting the further application of solar cells.

Two main approaches have been investigated to reduce costs -

a) The use of optical concentration systems

b) The use of low cost, non-crystalline semiconductor films such as amorphous silicon, cadmium telluride and copper indium selenide

CRYSTALLINE SOLAR CELLS

Modern crystalline solar cells can be made from single crystal silicon, gallium arsenide, indium phosphide or other semiconducting materials.

For simplicity, we will mainly consider crystalline silicon solar cells to develop a basic understanding of their operation.

PURE SILICON

Silicon atoms have four electrons in the outer orbital, each of which wants to form a bond with an electron from another adjacent atom. These bonds are called covalent bonds. The silicon forms a crystal with a diamond like structure.

Two electrons are involved in the formation of each bond. The density of silicon atoms is approximately $10^{28}m^{-3}$ or $10^{22}cm^{-3}$

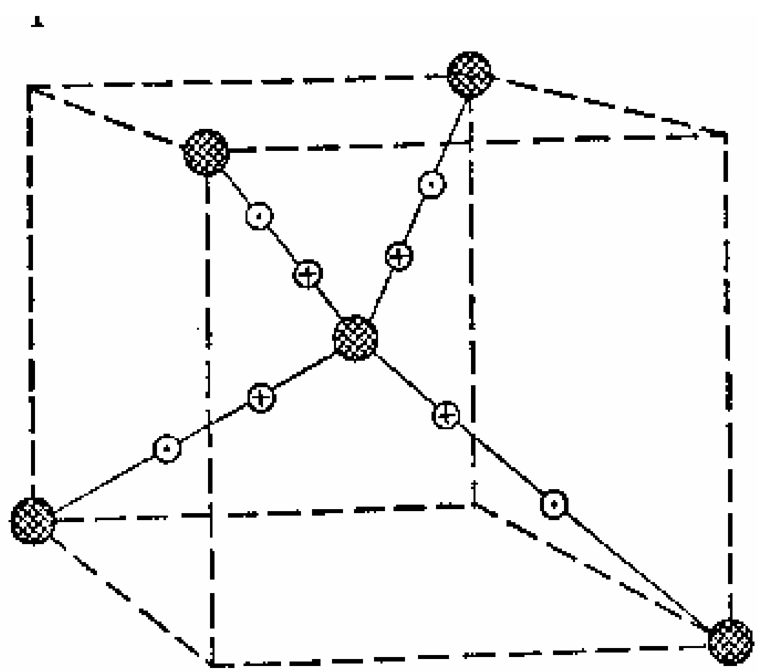


FIG. 4.6. A silicon atom with its four nearest neighbours (solid spheres). The spheres with crosses represent the four valence electrons of the central atom. The spheres with dots represent shared electrons from the four neighbours.

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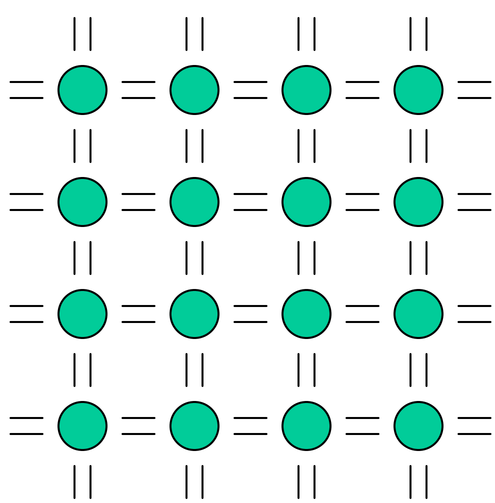
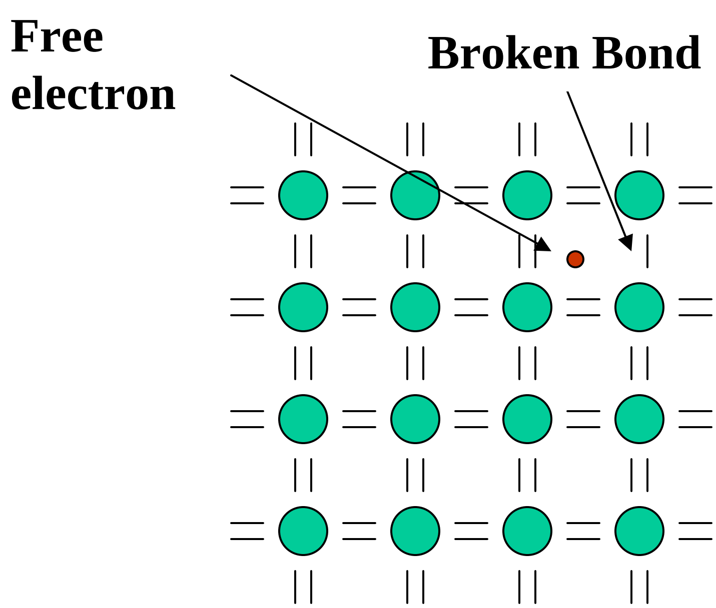
Simplified 2D representation



PURE SILICON

At zero temperature (0K) all the outer electrons are involved in bond formation, so there are no free electrons and no possibility of conduction due to electrons moving.

At room temperature (~300K) a few electrons gain enough thermal energy to break one of the bonds and become free electrons, able to move round in the crystal lattice.



PURE SILICON

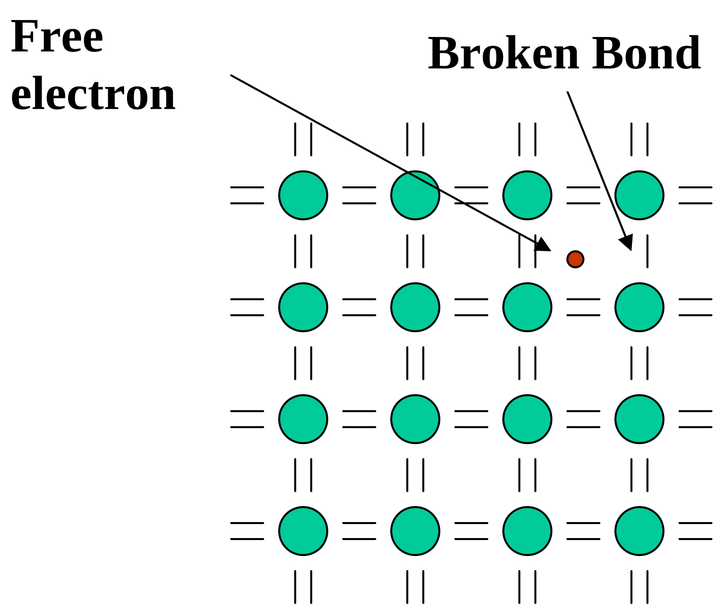
Every "free" electron leaves behind a free hole.

N^o of free electrons = N^o of free holes

$$n = p = n_i = p_i$$

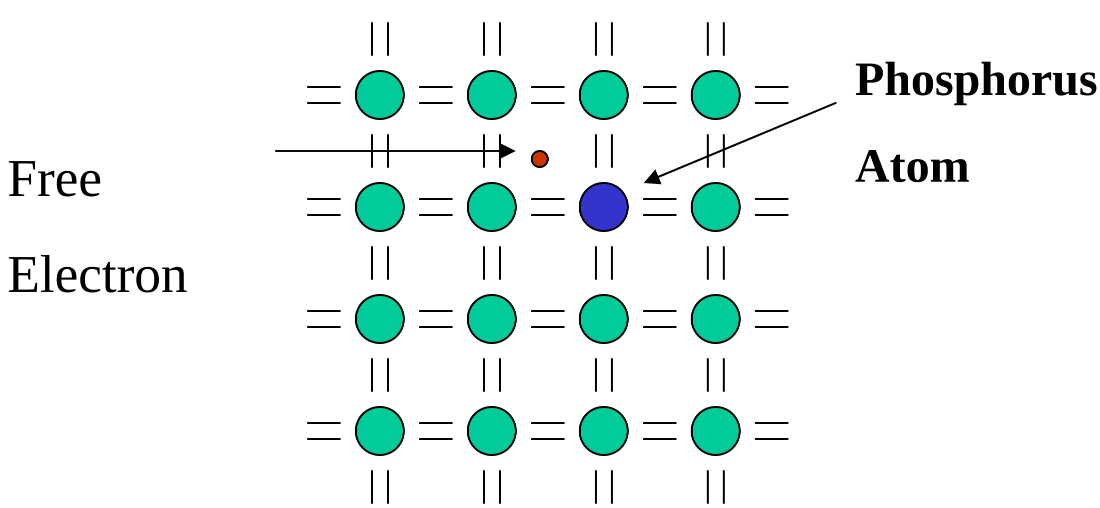
n_i , p_i are both the intrinsic carrier density

$n_i \sim 10^{10}$ cm^{-3} at 300K in silicon



N-doped (or n-type) SILICON

Some of the silicon atoms can be replaced by impurity atoms. The impurity atoms may have a different number of electrons in the outer shell. For example, phosphorus has five electrons in the outer shell. When a phosphorus atom is incorporated into the crystal lattice instead of a silicon atom, there is a spare electron which is not tied into a bond. This electron can move around, so is called a conduction electron.

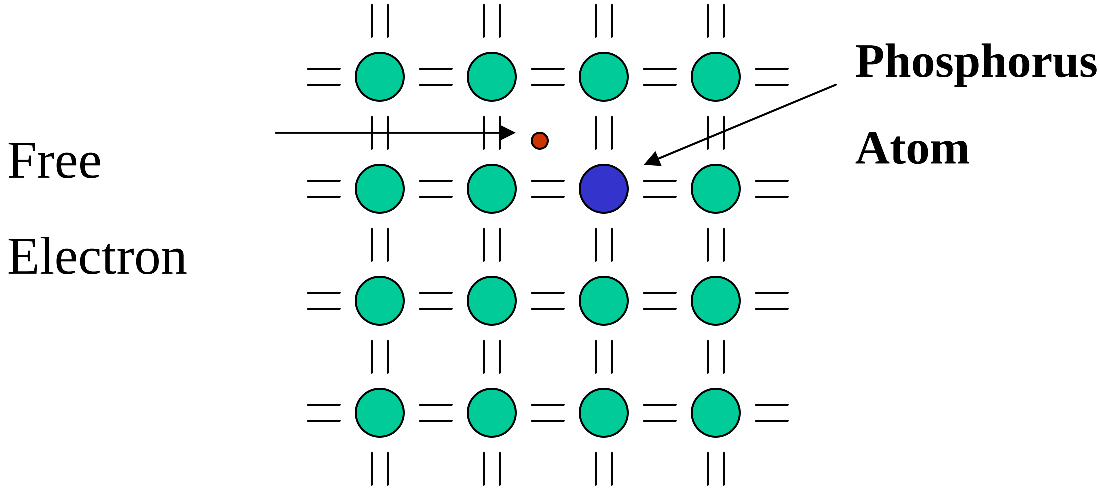


N-doped (or n-type) SILICON

If N_d cm^{-3} phosphorus donor atoms replace silicon atoms, then each donor atom results in one conduction electron, but no corresponding hole.

Therefore $n = N_d >> n_i$

Values of N_d are typically in the range 10^{15} - 10^{19} cm^{-3}

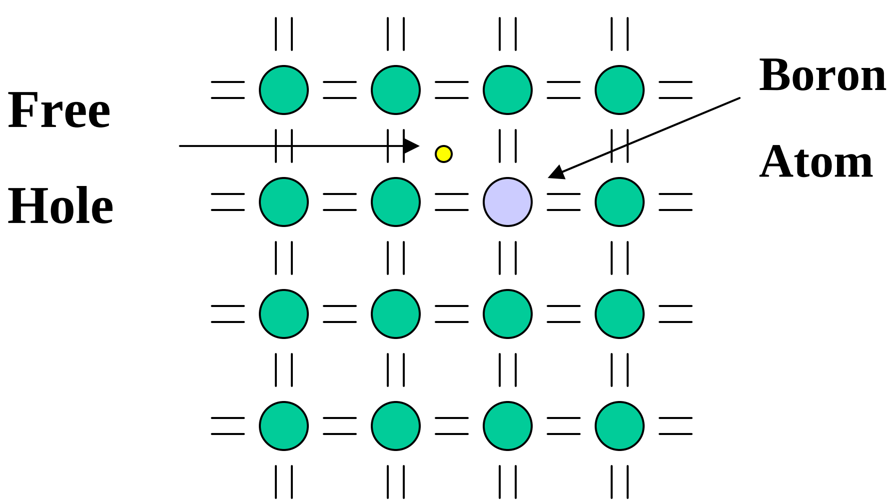


P-doped (or p-type) SILICON

If silicon atoms are substituted with acceptor atoms such as boron, which has only three electrons in the outer shell then each acceptor atom results in one hole, but no corresponding electron.

Therefore $p = N_a >> n_i$

Values of N_a are also typically in the range 10^{15} - 10^{19} cm^{-3}



Generation and Recombination of Electrons and Holes in Intrinsic Silicon

In pure silicon, free carriers are only produced by thermal or optical bond breaking, so equal numbers of electrons and holes are produced (electron-hole pairs)

$$\text{ie} \quad n_i = p_i$$

electron-hole recombination, R, is proportional to the number of electrons and holes

$$\text{ie } R \propto n_i \quad \text{and} \quad R \propto p_i$$

So, $R \propto n_i \; p_i = r \, n_i \; p_i = r \, n_i^2 = r \, p_i^2$

where r is a constant of proportionality, the recombination coefficient

Generation rate = Gi (T) pairs/second/m^3

In equilibrium

Generation rate = Recombination rate, so

$$Gi = r \, n_i^2$$

Generation and Recombination of Electrons and Holes in Doped Silicon

In doped silicon $n \neq p$

Recombination rate $R_d \;\alpha\; n \;\alpha\; p$

So $R_d = r\, n\, p$

Generation rate, Gd(T) = Gi(T)

if the temperature is the same

In equilibrium, $Gd = Gi = r\, n\, p = r\, n_i^2$

So, $np = n_i^2$ = constant (for a given T)

Consequently

In n-type material, $n \uparrow$ and $p \downarrow$

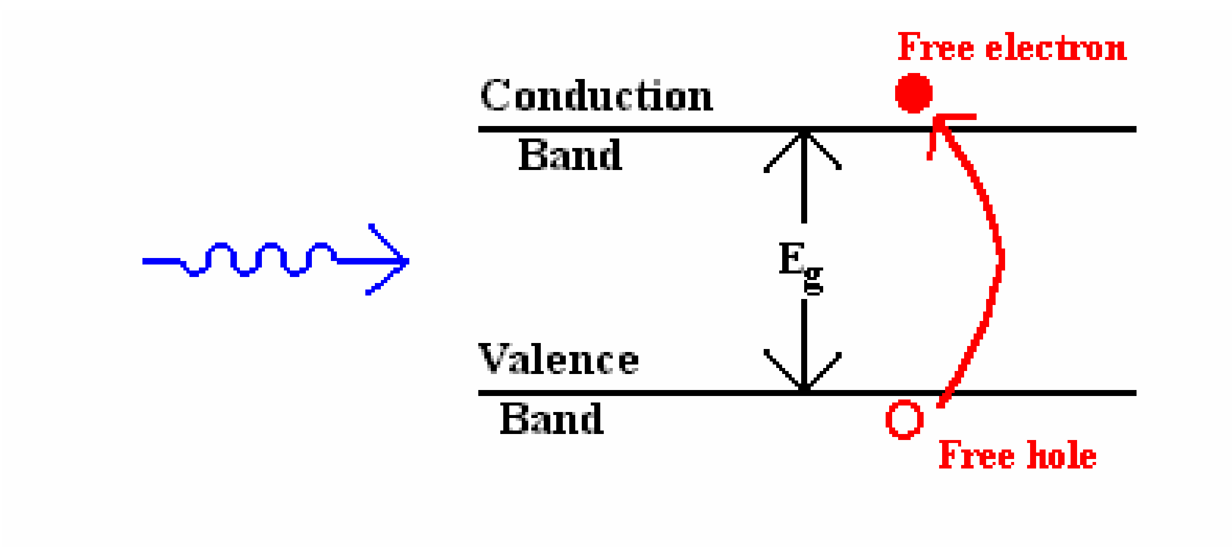
In p-type material, $p \uparrow$ and $n \downarrow$

So, if $n_i = 10^{10} cm^{-3}$ and $N_d = 10^{16} cm^{-3}$

Then $p = 10^4 cm^{-3}$, since $n_i^2 = 10^{20} cm^{-3}$

Photoexcitation of Carriers

By shining light on a semiconductor, bonds can be broken to create an electron-hole pair. The minimum energy required to achieve this is equal to the band gap of the semiconductor, E_g, which is the energy required to excite an electron from the valence band to the conduction band.



Photoexcitation of Carriers

Each photon has an energy given by

$$E = h\,\nu$$

where h = Planck's constant

and ν = the frequency of the light

So, if $h\,\nu > E_g$, electron hole pairs are produced

Since $\nu\,\lambda = c$, the speed of light, then for electron-hole pair generation, we can rewrite the equation as

$$\lambda_{max} = hc / E_g,$$

As $c = 3x10^8$cm/s, $h = 6.62x10^{-34}$Js and

$e = 1.602x10^{-19}$C, then

$$\lambda_{max} = 1.24 / E_g \text{(in electron volts)}$$

All wavelengths above λ_{max} <u>cannot</u> create electron-hole pairs in the semiconductor - the semiconductor is transparent at these wavelengths

Photoexcitation of Carriers

For example, silicon has a band gap, E_g , of 1.1eV.

So, since $\lambda_{max} = 1.24 / E_g$

Then $\lambda_{max} = 1.24/1.1 = 1.127\mu m$

So illumination with any wavelength below 1.127 μm will be able to create electron hole pairs and the light will be absorbed.

Any wavelength above 1.127μm will be unable to create electron hole pairs and will be transmitted by the semiconductor, since it will be transparent to the illumination.

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END OF LECTURE 1

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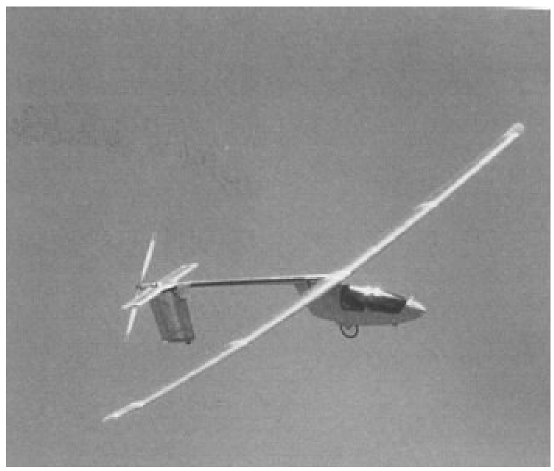

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Lecture notes :
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