Solid States Electronics a.k.a. fresh new history

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Introduction

Start with the oldest, complex and boring ish

Solid State Electronics

Materials: basic behavior

Crystals

Bond $\cdots$, Covalent Bond

Disclaimer

- Whole material seen in class as well as lectures are available either upon request or in my site
- Whole information is copyleft (see creative commons)
- It is your duty to attend lectures, submit your reports, excel your exams, attend the lab and read, read, read $\cdots$
- Your textbook is Microelectronic Circuit Design by Richard C. Jaeger
- Also, it is recommended Microelectronics by Sedra
- Book with my TA in case you required further assistance
- *Enjoy the ride*, **the arriving place will always be there**$\cdots$

Your Milestones

There are quite a few thing in this lovely pale blue dot that we, at the moment, do not have any idea how they work due to our rather poor understanding of Physics, Math, Chemistry and other Sciences. Nevertheless, we're looking for anything that seems to behave weird or do not match the knowledge that we have.

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- It has a large band gap and both, the valence and conduction bands, are displaced form one each other

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- The ban gap can be engineered to fit our requirements
- The valence and the conduction bands are "usually" one on top of the other to control the amount of energy required to make them work.

Semiconductors

In here, there are a few of the key elements used to fabricate semiconductors and the technology that we're currently developing. **Not ll of them**.

TABLE **2.2**
Portion of the Periodic Table, Including the Most Important Semiconductor Elements (shaded)

IIB	IIIA	IVA	VA	VIA
	5 B Boron 10.811	6 C Carbon 12.01115	7 N Nitrogen 14.0067	8 O Oxygen 15.9994
	13 Al Aluminum 26.9815	14 Si Silicon 28.086	15 P Phosphorus 30.9738	16 S Sulfur 32.064
30 Zn Zinc 65.37	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.922	34 Se Selenium 78.96
48 Cd Cadmium 112.40	49 In Indium 114.82	50 Sn Tin 118.69	51 Sb Antimony 121.75	52 Te Tellurium 127.60
80 Hg Mercury 200.59	81 Tl Thallium 204.37	82 Pb Lead 207.19	83 Bi Bismuth 208.980	84 Po Polonium (210)

TABLE **2.3**
Semiconductor Materials

SEMICONDUCTOR	BANDGAP ENERGY E_G (eV)
Carbon (diamond)	5.47
Silicon	1.12
Germanium	0.66
Tin	0.082
Gallium arsenide	1.42
Gallium nitride	3.49
Indium phosphide	1.35
Boron nitride	7.50
Silicon carbide	3.26
Silicon germanium	1.10
Cadmium selenide	1.70

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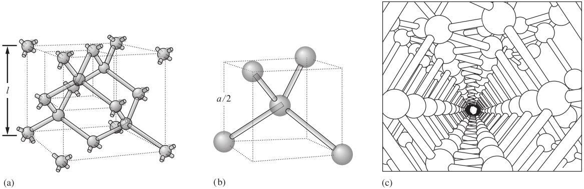
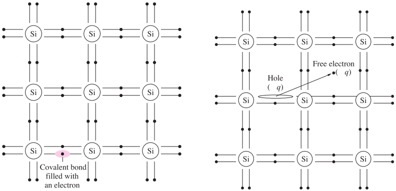
- the energy bands are, in some cases, mixed

Covalent Bond



Silicon crystal lattice structure, diamond configuration. a).- Diamond lattice structure. b).- Corner zoom. c).- Nice pic...



2D Si lattice at 0 K-ish that share covalent bonds complete. Whilst, Electron-pair is generated when covalent bond is broken.

Hole-electron pair is the milestone for whole technology as we know it. Analyze how much of those are within a crystal is key. This is why, we calculate the intrinsic carrier density n$_i$ (cm^{-3}) defined by:

$$n_i^2 = BT^3 \exp\left(-\frac{E_G}{kT}\right)$$

where

E_G = semiconductor bandgap energy in eV (electron volts)
k = Boltzmann?s constant, 8.62 10^{-5} eV/K
T = absolute temperature, K
B = material-dependent parameter, 1.08 $\times 10^{31}$ K^{-3} cm^{-6} for Si

Intrinsic Carrier Concentration

By using two materials such as those from group II-IV or III-V, it is needed to know the intrinsic carrier concentration in order to know how much current can it drive due to the bonds are broken and a pair electron-hole is created. For a positive charge (q^+), it is defined hole density represented by $\mathbf{p}+$ (hole/cm^{-3}). Similar as for **n**. $n = n_i = p$. This is why the electron-hole concentration is defined as:

$$pn = n_i$$

This consideration is valid if the semiconductor is in thermal equilibrium and it has not any sort of external stimulus.

Mobility

While an electric field is applied, the electric charge particles (positive) will move in the same direction as the electric field, this movement is called as *drift* and the resulting current is called as **drift current**. While negative charges drifts in the oposite direction of the applied field.
At low fields, carrier drift velocity v (cm/s) is proportional to the electric field $\mathbf{E}$, the proportionality constant is called mobility μ

$$v_n = -\mu_n \mathbf{E} \qquad\qquad v_p = -\mu_p \mathbf{E}$$

$v_n \rightarrow$ velocity of electrons (cm/s)
$v_p \rightarrow$ velocity of holes (cm/s)
$\mu_n \rightarrow$ electron mobility, 1350 cm^2/Vs for intrinsic Si
$\mu_p \rightarrow$ hole mobility, 500 cm^2/Vs for intrinsic Si

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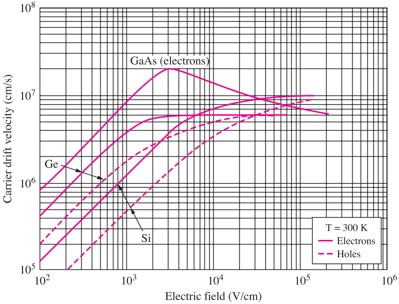
- 

Resistivity for Intrinsic Silicon

By using whole information that we've, so far, it is possible to calculate the current densities for p$^+$ and h$^-$: j_n^{drift} and j_p^{drift}

$$j_n^{drift} = Q_n v_n = (-qn)(-\mu_n E) = qn\mu_n E \quad A/cm^3$$

$$j_p^{drift} = Q_p v_p = (+qp)(-\mu_p E) = qp\mu_p E \quad A/cm^3$$

where, $Q_n = (-qn)$ and $Q_p = (+qp)$ are the charge densities for h$^+$ and e$^-$. Total dritf current is defined as:

$$j_T^{drift} = j_n + j_p = q(n\mu_n + p\mu_p)E = \sigma E$$

Resistivity for Intrinsic Silicon

The **electrical conductivity** is defined as

$$\sigma = q(n\mu_n + p\mu_p) \quad (\Omega cm)^{-1}$$

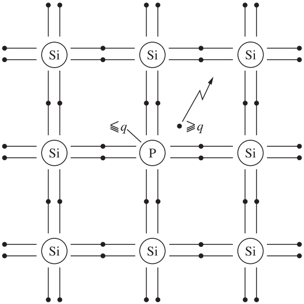
Resistivity is reciprocal to conductivity:

$$\rho = \frac{1}{\sigma} \quad (\Omega cm)$$

NOTE: it seems a bit odd that resistivity units are Ω cm, nevertheless, from total current density it is possible to obtain those units.

$$\rho = \frac{E}{j_T^{drift}} \rightarrow \frac{V/cm}{A/cm^2} = \Omega cm$$

As Potter was or wasn't a Muggle or impure



To be continue $\cdots$