HETEROSTRUCTURE P-N JUNCTIONS (nptelhrd youtube video)

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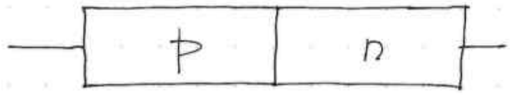
PN junctions are of types:

1> HOMOJUNCTION: A junction between same material, but different doping concentrations / types. Eg: p-type / n-type silicon.

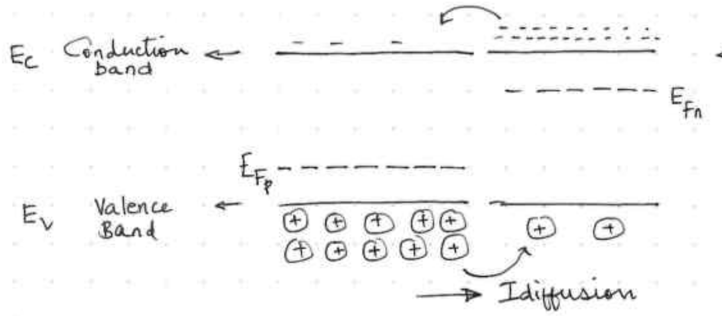
2> HETEROJUNCTION: A junction between two different materials with different bandgaps

3) SCHOTTKY JUNCTION: A junction between metal and semiconductor.

Let us go through a brief review of homojunction band energy diagrams as it will lay the foundation for heterojunctions. Consider a homojunction between a p- and n-type silicon material:



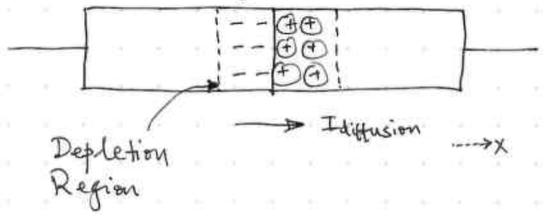
, and draw the energy band diagram before contacting them.



The conduction and valence band energies are the same, because they are the same material: Silicon

But fermi levels differ due to doping of p- and n-types.

There are a large number of electrons on n-side, and a large number of holes on p-side that will diffuse over to the other side due to concentration gradient, leaving behind holes in the n-side and electrons in the p-side, creating depletion region



The resulting field, or built-in potential, causes a drift current to flow.

At equilibrium: $i_{diffusion} + i_{drift} = 0$, and it can be shown that $\frac{dE_f}{dx} = 0 \Rightarrow E_f$ is independant of X. E_f is a constant.

$\boxed{\text{Fermi level is a constant}}$

BAND BENDING

Now, let us consider the energy levels when pn junction is in equilibrium.

Let $\rho(x)$ be the 1-D charge density in the depletion region.

According to Gauss' law:

$$\nabla \cdot E = \frac{\rho(x)}{\epsilon}$$

In 1-D: $\dfrac{dE}{dx} = \dfrac{\rho(x)}{\epsilon}$

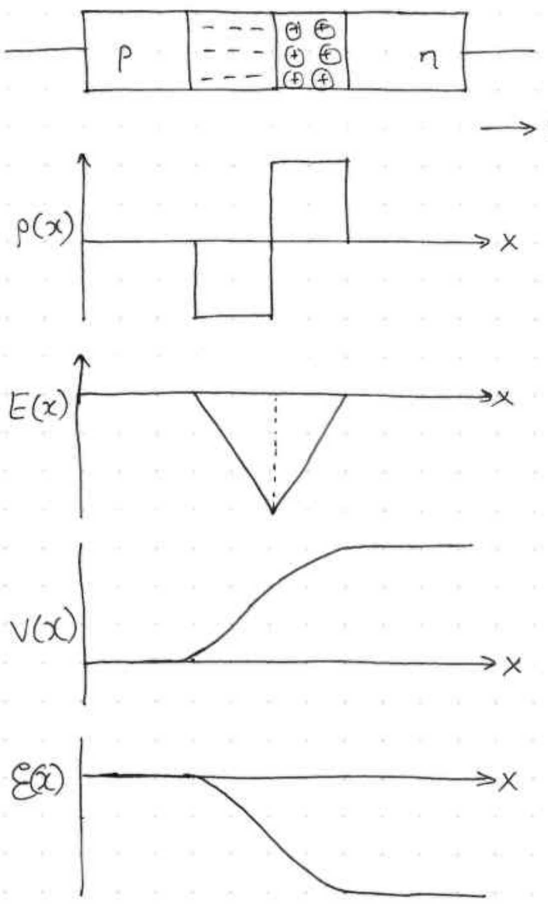
or $E(x) = \int \dfrac{\rho(x)\,dx}{\epsilon}$

Calculating potential: $E = -\dfrac{dV}{dx}$

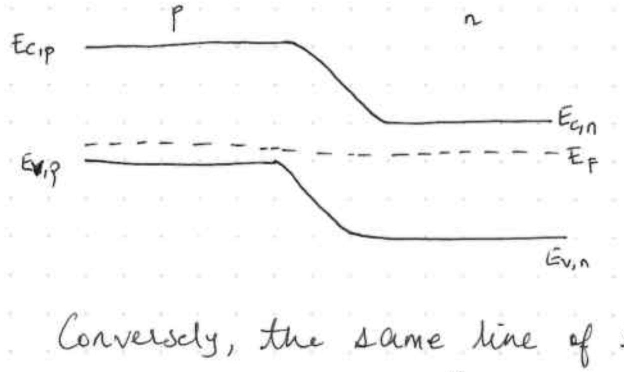
or $V(x) = -\int E(x)\,dx$

And Energy $\mathcal{E}(x) = (-e)\,V(x)$

The migration of charges across the junction has caused the energy to vary across the depletion region.

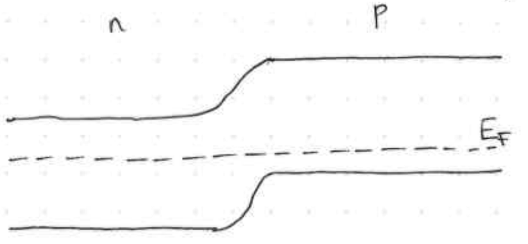


Thus, the bands of energy are said to "bend" to accomodate this continuous variation of energy. Now, we are able to draw the band diagram of a p-n homojunction.



← This is obtained by adding $\mathcal{E}(x)$ to the energy diagrams of the p & n-type materials.

Conversely, the same line of reason is applicable to an n-p junction

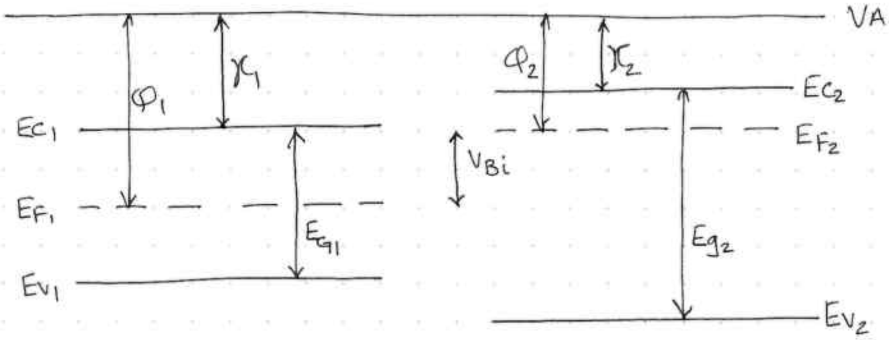


ANDERSON'S RULE:

Before we go deep into constructing energy diagrams for heterojunctions; we should understand Anderson's rule.

> When constructing an energy band diagram, the vacuum levels of two semiconductors on either side of the hetergjunction should be aligned.

Once vacuum levels are aligned, electron affinity (energy required to free an electron from conduction band) and band gap values can be used to construct an energy diagram.

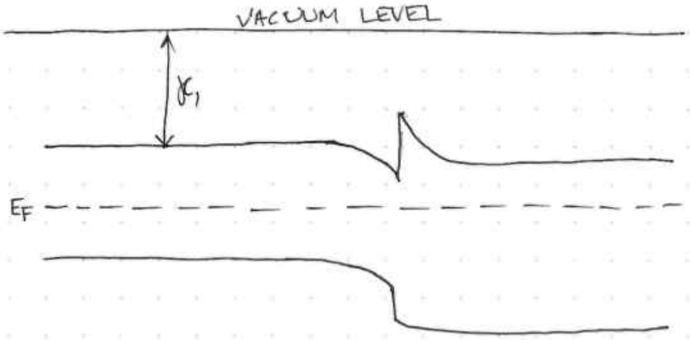


χ = electron affinity
Φ = work function
E_g = band gap
$V_{bi} = \Phi_1 - \Phi_2$ built in potential
E_F = Fermi level
E_c = Conduction Band
E_V = Valence Band

Alaways remember that electrons will flow from the higher fermi level to the lower one.

Knowing this, you can determine the charge distribution at equilibrium and use that to calculate E, V, and $\mathcal{E}$, like the case of a homojunction p-n, earlier.

In the above example, electrons will flow from 2 to 1, resulting in the following:

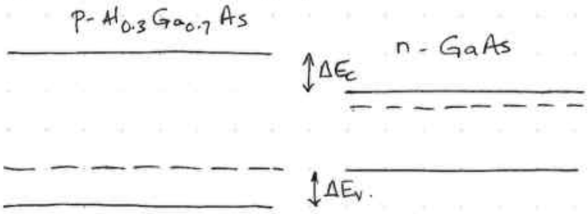


χ and E_g IN Common Semiconductors

	χ (ev)	E_g (ev)
Si	4.05	1.12
Ge	4.0	0.66
GaAs	4.07	1.43
InP	4.35	1.35
Al As	2.62	2.16

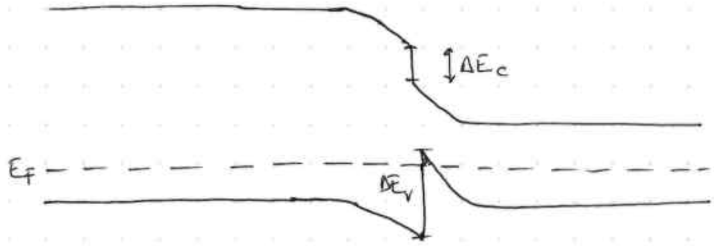
HETEROJUNCTIONS (nptelhrd youtube video continued)

In a heterojunction, we contact two dissimilar materials with different bandgaps. Consider an example of p-AlGaAs & n-GaAs.



Electrons will flow from n-GaAs to p-AlGaAs, making the depletion region negative in AlGaAs and positive in GaAs.

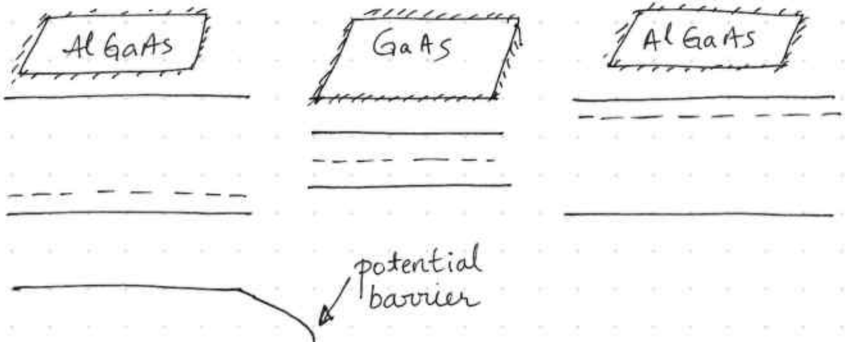
As a result, the n-GaAs bands will bend down till Fermi levels align. However, due to the bandgap differences in Ec and Ev, there will be an abrupt energy change at the interface as shown below:



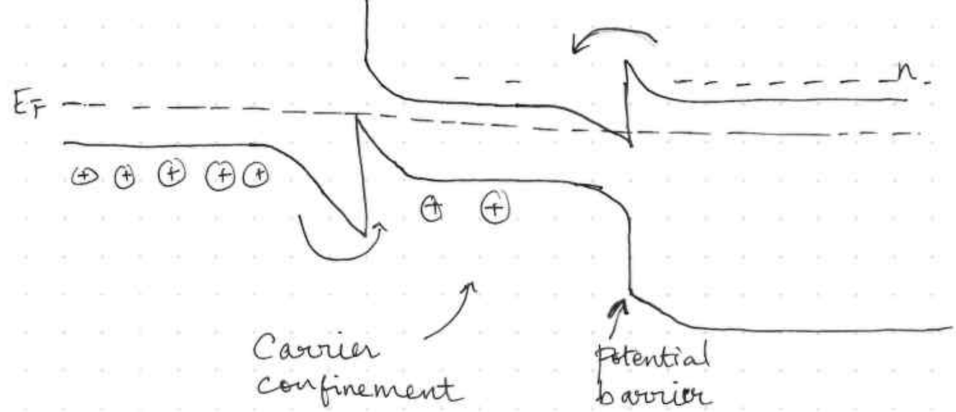
This shows energy diagram at equilibrium.

Band diagrams for other heterostructures can be drawn in a similar way.

For a brief moment, consider double heterostructures, because there is something fascinating that happens in terms of energy. Consider a AlGaAs - GaAs - AlGaAs system:



Thickness of sandwiched GaAs layer is in our control



If this junction is forward biased, n-side energy moves up by $\mathcal{E} = (-e)(-V)$, spilling electrons and holes in the GaAs layer. But these carriers are confined by the presense of potential barrier ⇒ high charge density