Solid State Physics

SEMICONDUCTOR DEVICES

Lecture 26

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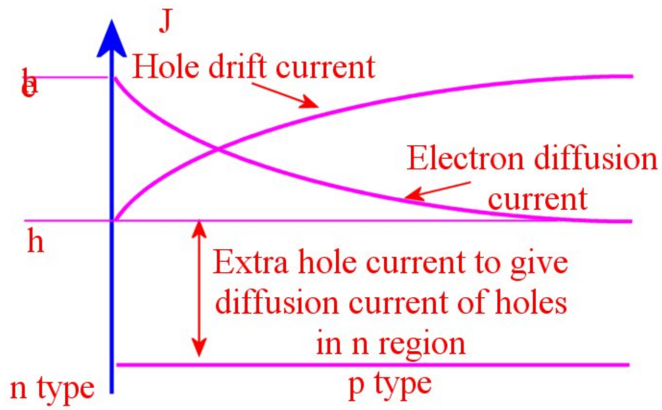
9.9 Heterojunctions (cont'd)

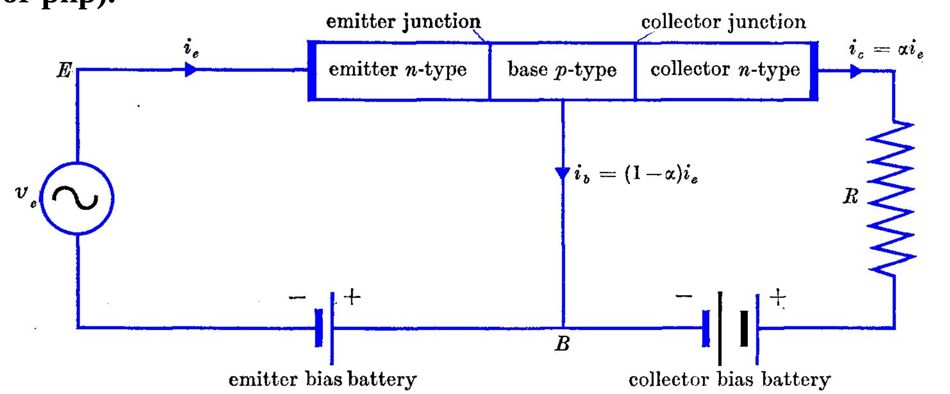
In the diode, there is a change through the barrier region in what carriers dominate the current flow:



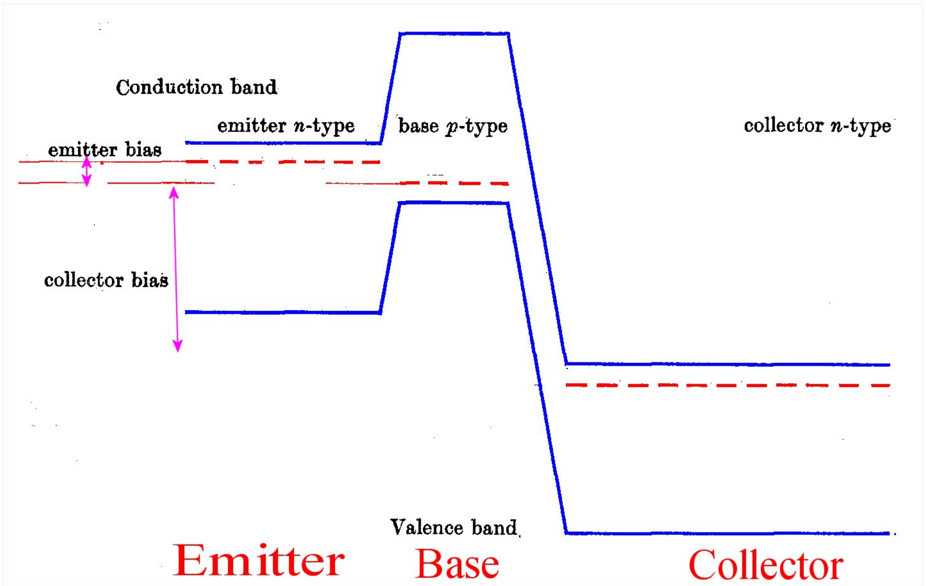
Typical diffusion length, l_e or l_h, is about $1\ \mathrm{mm}$, much larger than the width of the depletion zone (about $1\ \mu\mathrm{m}$.

9.9.1 Junction transistor

The junction transistor is two diodes stuck back-to-back (either npn or pnp).



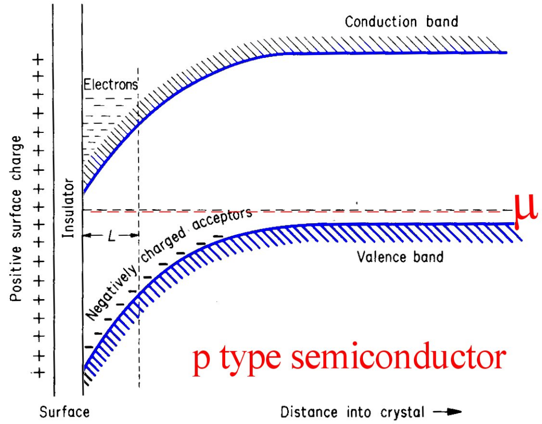
The signal voltage $\mathcal{V}_S$ added to the emitter voltage alters the current through the collector, giving an amplified voltage across the load resistance R.



Any change in base-emitter voltage causes a large change in the electron current injected into the base. Most of these electrons flow on into the collector.

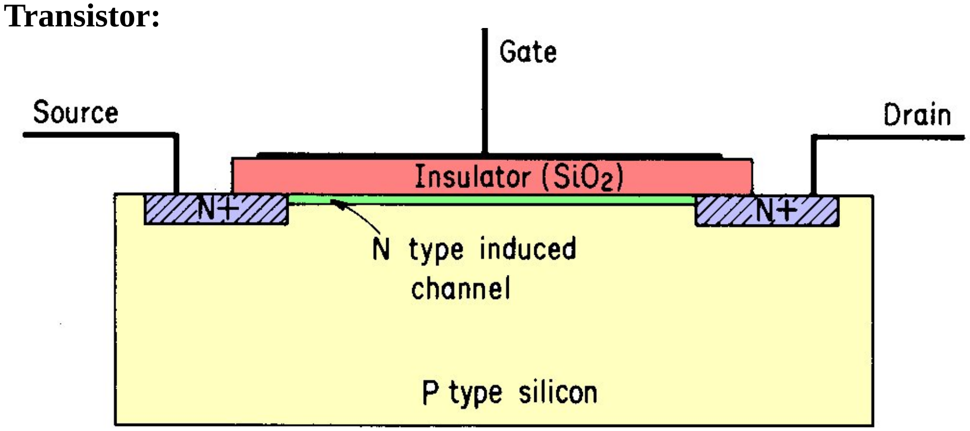
9.9.2 Field effect transistor

We can influence carrier densities in a material by applying a potential: here is a Metal-Insulator-Semiconductor (or Metal-Oxide-Semiconductor, MOS) system.



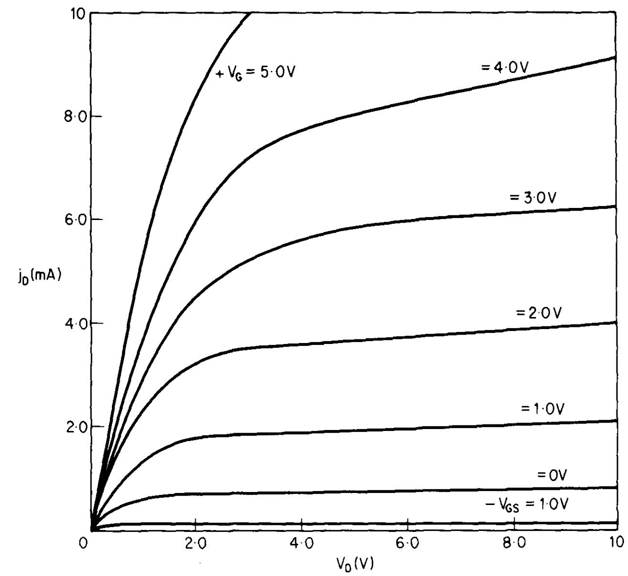
That is, with a voltage we can induce a density of *free electrons* in p-type material – called an *inversion region* – band bending effects from Poisson's equation as before.

This gives us a MOSFET, or Metal Oxide Semiconductor FIeld Effect Transistor:



Altering the gate voltage alters the number of electrons in the induced inversion layer: current can flow between the heavily n-type doped regions.

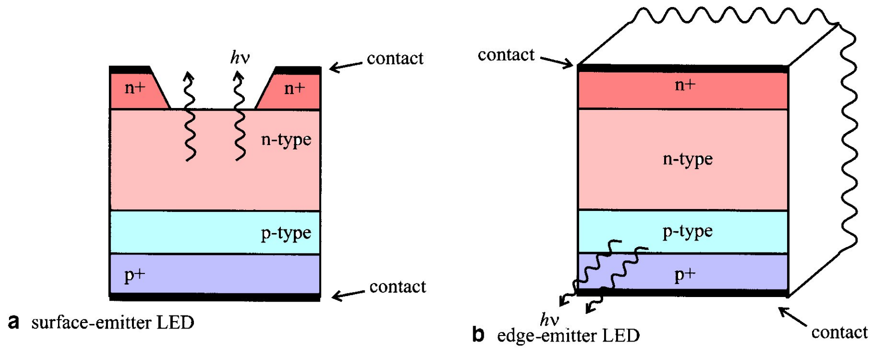
Current-voltage characteristics of MOSFET (Mullard type BFW96)



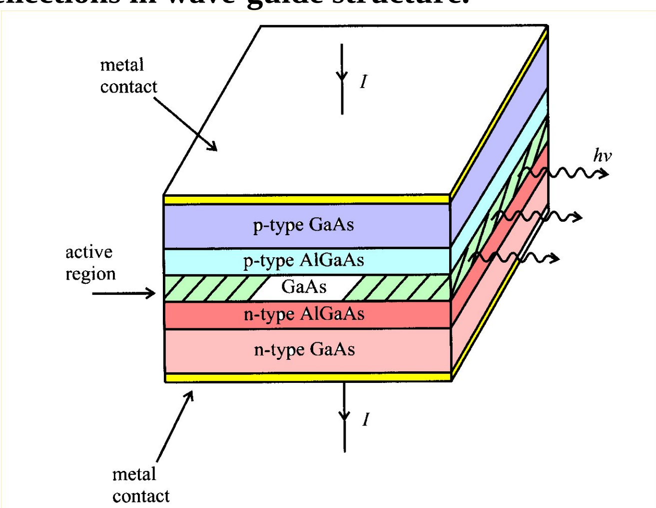
The layer of electrons under a charged plate is an example of a *two-dimensional electron gas*. 2-D gases can also be formed in sandwich structures of materials with different band gaps. Narrow layers give free carrier motion in-plane, quantised states in the perpendicular direction – *quantum well devices*.

9.9.3 Light-emitting diodes

These exploit the recombination that occurs when electrons in a forward-biased diode recombine with the holes. The trick is to alter the material to favour recombination which gives out energy as light rather than heat. Also alter the composition (e.g. $\mathrm{GaAs_{1-x}P_x}$) or add dopants such as zinc or oxygen. Can get blue from InGaN.



Given a *population inversion* (*large* populations of electrons in the conduction band and holes in the valence band) we can get *lasing action*. This can be achieved with *degenerate doping* – $E-\mu$ comparable with or less than $k_\mathrm{B}T$. Also need to set structure up in resonance - multiple reflections in wave-guide structure.



9.9.4 Solar cells

In a solar cell, a photon is absorbed to create an electron-hole pair, these carriers move to produce a current proportional to the photon flux.

$$I = I_0 \left[\exp\left(\frac{eV}{k_\mathrm{B}T} \right) - 1 \right] - I_p,$$

where I_p is the photo-generated current. Characterised by the *quantum efficiency*, η, the number of electrons generated per photon. Typically about 0.7 for a Silicon solar cell.