EEE105 – Summary Sheet – Lectures 7-14

1. Semiconductors are covalently bonded materials with two shared electrons in each of four bonds around each atom
2. The bonding state can also be known as the valence band and the excited state, where a particle is out of the bond is the conduction band.
3. A free electron is one out of the bond, in an excited state and a hole is the absence of an electron in a bond.
4. We can increase the number of free electrons (holes) by doping a group IV semiconductor with a group V (group III) element.
    a. Material where there is a majority of electrons (hole) as charge carriers is called n-type (p-type)
5. In general in a semiconductor both electrons and holes can contribute to the conductivity and we must add their components together to get the overall conductivity.
6. In a semiconductor electron-hole pairs are being thermally generated and recombining all the time, giving rise to the intrinsic concentration of charge carriers.
7. From this in doped material we can show that $\boxed{n_i^2 = pn_p = np_n}$ depending on the doping, where n_p and p_n denote minority carrier concentrations.
8. Excess minority carrier holes will recombine at a rate given by $\boxed{\delta p(t) = \delta p_0 \exp(-t/\tau_h)}$ where τ_h is the hole minority carrier lifetime
9. Excess minority carrier holes will diffuse into n-type material before they recombine. The characteristic diffusion length they reach is given by $\boxed{\delta p(x) = \delta p_0 \exp(-x/L_h)}$ where L_h is the hole minority carrier diffusion length.
10. In a p-n junction electrons and holes will diffuse across the junction until the electric field set up by the ionized acceptors and donors is sufficient to oppose further diffusion.
11. There is a region where all the free carriers have recombined, called the depletion region.
12. The barrier to electron and hole diffusion in a p-n junction is called the ***built-in potential.***
    a. The dominant term governing the value of the built-in potential is the ionisation energy of the material (energy required to move an electron from the valence band to conduction band).
13. Under forward bias the built-in potential is reduced, allowing diffusion to occur and current to flow. The amount of current flowing is given by the diode equation: $\boxed{J = J_0\left[\exp\left(\frac{qV}{kT}\right) - 1\right]}$ where J_0 is the saturation current density.
14. The term J_0 has a component due to electrons diffusing into the p-type material where the recombine (***the electron current***) and a component due to holes diffusing into the n-type material where the recombine (***the hole current***).
    a. The ratio of electron to hole current can be approximated by the ratio of the conductivity of the n-type material to the conductivity of the p-type material.
15. The forward biased p-n junction can emit light when the electrons recombine with holes – this is the principle of the Light Emitting Diode.
16. In reverse bias the barrier preventing electron and hole diffusion across the junction increases. There is only a small current flow due to thermal generation of electrons and holes in or near the depletion region.
17. A reverse biased p-n junction if it absorbs light can show a significant increase in current flow giving a photodiode. Under zero-bias the effect of the built-in potential in pushing electrons into the n-type material and holes into the p-type material also leads current flow – solar cell operation.
18. The depletion region thickness on either side of the p-n junction depend on the doping. The higher the doping the thinner the depletion width on that side of the junction.
    a. For junctions where one side is much more heavily doped than the other we can assume all the depletion region thickness is on one side of the junction.
    b. For such a junction the depletion region thickness can be given by $\boxed{d_j = \sqrt{\frac{2\varepsilon V_0}{qN_d}}}$ (where *p*>>*n*)
19. The depletion region thickness can change with applied bias (replace V_0 with V_0-V (forward bias) or V_0+V (reverse bias)
20. The depletion region can be treated as the dielectric in a parallel plate capacitor giving (for *p*>>*n*): $\boxed{C_j = A\cdot\sqrt{\frac{q\varepsilon N_d}{2V_j}}}$ where V_j is the built-in potential plus or minus the reverse or forward bias voltage.