Semiconductors & Defects: Exercise 7 (21 Dec. '21)

General remark: Always try to come up with a short answer that catches the essence.

21. Calculation: Derive the result presented in the lecture, that in Boltzmann approximation, $[1 - f(E_{DL})] / f(E_{DL})$ gives $\exp[-(E_F - E_{DL})/(kT)]$.

22. Discussion only, no formulae, no details: To calculate the recombination rate for an indirect semiconductor, what is most important in the SRH model regarding the underlying microscopic notions? What applies in general, and what specifically when considering majority and minority charge carriers?
(The idea behind this task is to catch the essence of the SRH model: What do you need to have understood well enough so that you are, at least in principle, able to derive the formulae yourself?)

23. Discussion and formulae: What does the SRH model finally give (under certain conditions) as an explicit result for the minority carrier lifetime in an indirect semiconductor? What are those "certain conditions" for which this result for the lifetime is obtained? What are the main technologically adjustable factors that limit the minority carrier lifetime in an indirect semiconductor? How does the energetic position of a defect state ("deep level") influence the lifetime in an indirect semiconductor, and what is the deeper reason that there is a particularly relevant energy range for its influence?

25. Calculation and discussion: Have a look at the Advanced module "Solving the Poisson Equation for pn-Junctions" (https://www.tf.uni-kiel.de/matwis/amat/semi_en/kap_2/advanced/t2_3_3.html). Find (some of) the errors in the calculation, and try to correct them (yes, just try; it is sufficient to make suggestions how it could be "repaired"). Point out what is unclear to you. Find the main error in the illustration showing the whole situation in one drawing. (Hint: The latter is possible by just looking at the drawing itself; one doesn't need to go through all the equations to find the relevant error.)

29. Discussion and formula: What is meant by the term "dielectric relaxation time"? How is the dielectric relaxation time related to the Debye length? Describe (i) the generally relevant physics leading to the dielectric relaxation time and (ii) the "physical effect" expressed by the dielectric relaxation time. Why does that imply that lateral charge equilibration for minorities (*i.e.*, the reduction of a lateral variation of the minority carrier density) is always driven just by diffusion?

30. Calculation: Consider a p–n junction in thermal equilibrium. The minority carrier densities can be obtained (i) from the mass action law, $n_{min}\, n_{maj} = n_i^2$, valid at each side of the junction separately, and (ii) via a Boltzmann factor from the corresponding majority carrier density at the other side of the junction, as follows: $n_{min}^{\alpha} = n_{maj}^{\beta} \exp[-eV^{n}/(kT)]$. Here, α and β denote the p- and the n-side (or vice versa), and eV^{n} is the energy difference in any of the bands between p and n side ($V^{n} = \Delta E_F/e$ is also known as the built-in potential, with ΔE_F being the difference in the Fermi energies of the two bulk sides "before junction formation"). Show that these two approaches lead to the same result for the minority carrier densities.

(See next page for continuation)

31. Discussion (and maybe formulae): Starting from a p–n junction in thermal equilibrium, by which basic considerations can its theoretical treatment be extended to stationary non-equilibrium, brought about by an external voltage applied in forward direction?

32. Drawing, formulae, and discussion: Consider a p–n junction in thermal equilibrium: Draw the distribution of the electrons and holes across the space charge region (SCR). Given that there is a constant acceptor (donor) density N_A (N_D) in the p-type (n-type) region, how is the hole (electron) density related to the local value of the electrostatic potential $V(x)$, and how can, in principle, the band bending (*i.e.*, the spatial variation of the band edge) in the SCR be calculated? Write down the relevant equations (only those to be solved, not their solution)! Compare the example shown graphically in the solution of "Exercise 2.3.5-1" to the charge carrier distribution just drawn by you: What fundamental simplification has been made in the graphics shown in the solution of "Exercise 2.3.5-1"? (Indirect hint: It is correctly shown in this graphics that there is no band bending in the bulk regions outside the SCR – but why is this so?)

33. Discussion: Why and how does a p–n junction work as a diode (*i.e.*, as a rectifier)? What are the relevant charge carrier transport mechanisms? What is the physical reason for the current–voltage characteristic of a p–n junction being an exponential function?

34. Drawing and discussion: Draw the quasi-Fermi energies at a p–n junction under forward and reverse bias; describe the relevant physics.

35. Discussion: Have a look at the Wikipedia entry explaining holes in semiconductors (https://en.wikipedia.org/wiki/Electron_hole) and comment on its scientific quality: What errors and problematic aspects do you notice in the very first two paragraphs? *Important:* Do **not** try to fix it, just point out the problems. To do so, also think about possible consequences: What fundamental law of physics would be violated if the present version (as of 29 June 2021) of the explanation were correct?
(You might also have a look at the entries given in other languages about this topic – are they as bad, too?)