Semiconductors & Defects: Exercise 5 (07 Dec. '21)

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

12. Discussion: What are semiconductors (SCs) in general, and by which "condition" are only some of them (in principle; there are a few exceptions) of technological relevance? Explain the main differences between metals, semiconductors and insulators. Give examples for different kinds of SCs that can be formed by elements of the periodic table.

14. Discussion, drawing, and formula: Demonstrate the band-bending and the formation of a space charge region at the surface of a **p-type** semiconductor. Why is it called space charge region? Why is the surface charged at all? (Could there be a situation where it is not charged?) Show the directions of electric field lines. Specify the expression giving the width of the space charge region, and provide a microscopic interpretation of the involved quantities (*i.e.*, explain why those quantities influence the width of the space charge region the way they do it according to the formula).

16. Calculation and discussion: Derive the mass action law for an extrinsic semiconductor in a stationary non-equilibrium situation. Justify the approximations used, and discuss the factor representing the deviation from equilibrium. Where do the quasi-Fermi energies play an important role: (i) Within the bands or (ii) between the bands?

17. Discussion and formula: Describe the effective mass! How is it defined, and why do we use effective masses rather than the original mass? What is special about the effective mass of the valence band, and how is that specialty treated when holes are introduced? Sometimes we have two values of the effective masses for electrons or holes – where does that come from, and what does that imply?

18. Discussion and formula: What does the effective mass (may) depend on in arbitrary real-world 3D crystals? (Hint: Just look at its definition!) What may happen to the effective mass in 2D or 1D structures, compared to the 3D case? What is the practical consequence of the effective masses with respect to high frequency device applications: If there are different effective masses, which is the more beneficial one for high frequency applications, and why? Try to explain how "strained silicon" is helpful in that respect. (Consult the World Wide Web for basic information about "strained silicon".)

19. Discussion only, no formulae, no details: To calculate the recombination rate for a direct 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?)

20. Discussion and formulae: What is meant by the net recombination rate? What does the SRH model finally give (under certain conditions) as an explicit result for the minority carrier lifetime in a direct semiconductor? What are those "certain conditions" for which this result for the lifetime is obtained? What is the main technologically adjustable factor that limits the minority carrier lifetime in a direct semiconductor?

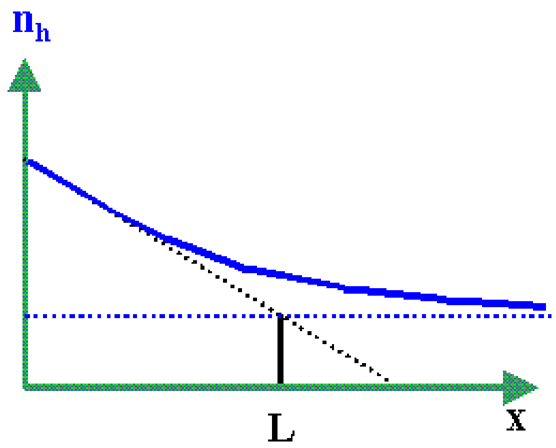
(See next page for continuation)

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?

24. Formulae and discussion: Look again at the following drawing from the last lecture, giving the actual minority hole density adjacent to the space charge region:



Why is it correct that the tangent of the starting slope crosses the reference line (for which n_h equals the equilibrium hole density) exactly at the diffusion length L?

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.)