Semiconductors & Defects: Exercise 7 (13 Dec. ’22)

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

17. Formula and discussion: Consider the SCR at the surface of a p-type semiconductor: 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).

19. Discussion and formulae: Consider an ideal p–n junction without the contribution of the space charge region.
    c) Now, consider an *asymmetrically* doped p–n junction, made from a direct semiconductor, under forward bias (*i.e.*, acting as an LED): Which side provides the larger contribution to the light output, the higher or the lower doped one? Why?

20. Discussion: Consider an ideal p–n junction without the contribution of the space charge region. What happens to the currents across the junction when the whole device is illuminated by light that can be absorbed by the semiconductor? What happens to these currents if only a part of the device becomes illuminated: What is the relevance of the position where the light is absorbed?

21. Discussion and formula: Download the conference proceedings paper “Classification of pre-breakdown phenomena in multicrystalline silicon solar cells” from MPI Halle/S. (https://www-old.mpi-halle.mpg.de/mpi/publi/pdf/9075_09.pdf). Figure 1 shows temperature-dependent reverse-bias characteristics, and Fig. 6 shows some DLIT images taken at –10 V for different temperatures (DLIT: dark lock-in thermography). In the text of the publication, no explanation is given for the temperature-dependent behavior of the reverse current shown in Fig. 6; it is only argued that a certain possibility is excluded – which one? Thus, what possible mechanism has (seemingly) been overlooked? To clarify if it is reasonable to indeed explain the observation shown in Fig. 6 by this possible mechanism, try to estimate the order of magnitude of this mechanism. (Yes, just try; in case you need specific solar cell data, send me an e-mail requesting them.)

22. 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 for the mobility of the charge carriers?

23. Discussion and formula: What does the effective mass (may) depend on in arbitrary real-world 3D crystals? (Hint: Just look at its definition!) What is the practical consequence of the effective masses with respect to high frequency device applications: If there are different effective masses (as it is typically the case for holes), 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”.) What may happen to the effective mass in 2D or 1D structures, compared to the 3D case? Why is there no effective mass in the 0D case?

24. 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 (and which do they have?): (i) Within the bands or (ii) between the bands?

25. Discussion only, no formulae, no details: To calculate the recombination rate for a direct semiconductor, what is most important in the approach presented in the lecture 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 theory: What do you need to have understood well enough so that you are, at least in principle, able to derive the formulae yourself?)

26. Discussion and formulae: What is meant by the net recombination rate? What does the recombination theory 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?

27. Discussion only, no formulae, no details: To calculate the recombination rate for an indirect semiconductor, what is most important in the Shockley–Read–Hall (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?)

28. 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?