Semiconductors & Defects: Exercise 6 (06 Dec. ’22)

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

13. Schematic drawing and discussion: Which pieces of fundamental information do we get about a semiconductor from its band structure? Name only those properties that we have touched in the lecture so far, and try to mention as many as possible. (Hint: A real-world semiconductor is a 3D object; how does that show up in the band structure?)

14. Calculation and discussion: Derive the mass action law for an extrinsic semiconductor in a stationary equilibrium situation, starting from the Fermi distribution for calculating the carrier densities in the bands. Justify the approximations used.

15. Calculation and discussion: Describe, in your own words, why in thermal equilibrium the Fermi energy is the same everywhere.

16. 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” (SCR)? What charges are there, and why? Why is the surface charged at all; could there be a situation where the surface is not charged? Show the direction of the electric field lines. In the SCR, why are the bands not flat anymore?

17. Formula and discussion: As in task #16, 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).

18. Formula and discussion: Similar to task #17, consider the SCR of a p–n junction: 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?