Semiconductors & Defects: Exercise 5 (29 Nov. '22)

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

9. Discussion, drawing, and formula: What is meant by an "extrinsic semiconductor"? Draw the schematic band diagram of an extrinsic SC having conduction band, valence band, donor level, and acceptor level. Specify the charge neutrality condition in an extrinsic SC, and explain why the various charges are counted this way. Which important quantity can be obtained from this condition (for a given temperature)?

11. 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.

12. Formulae and discussion: Explain the quantity "mobility": How is it defined, and how can it be written in the simple scattering time approximation – and why so? What are the main factors affecting the mobility of charge carriers, and in which way? How can these effects be understood on the basis of the model of nearly free electrons? How do these effects depend on temperature – and why so?

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.
a) How do forward and reverse current depend on temperature?
b) The forward current is a diffusion current of majority carriers. However, when *increasing* the doping levels of the bulk materials (and, therefore, also the majority carrier densities), this current is *reduced*. Why? (Hint: There are different ways to give the reason; think about those different possibilities.)
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?