<u>Semiconductors & Defects: Exercise 9 (18 Jan. '22)</u>

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

31. <u>Discussion (and maybe formulae):</u> 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?

33. <u>Discussion:</u> 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. <u>Drawing and discussion:</u> Draw the quasi-Fermi energies at a p–n junction under forward and reverse bias; describe the relevant physics.

35. <u>Discussion:</u> Have a look at the English 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?)

38. <u>Discussion:</u> What possibilities are there for the doping of compound semiconductors, especially of III-V materials? What is similar to the doping of group-IV materials, what is fundamentally different?

39. <u>Discussion:</u> What is "wavelength engineering"? How can it be achieved? What kind of technical questions and physical aspects must be kept in mind when realizing it? What is the special technical advantage of $Al_xGa_{1-x}As$? What limits usability of $Al_xGa_{1-x}As$ as an optoelectronic material?

40. <u>Discussion and drawing (maybe generated electronically):</u> When we discussed about task #32 last week, the idea behind the solution became clear, but in my eyes the final result wasn't fully convincing. We were able to find some errors here and there, but the "true" curves for the carrier densities at an asymmetrically doped p–n junction in thermal equilibrium remained unclear. Also, in the literature (WWW, books) I only found qualitative drawings that weren't fully satisfying. However, the more trustworthy ones at least hinted at a fact that we should reconsider:
    Why is it reasonable that, for an asymmetrically doped p–n junction, the crossing point between the electron and the hole density (*i.e.*, the position for which it holds that $n_e = n_h = n_i$) is **not** identical to the point where the underlying doping abruptly changes from n-type to p-type; where should this crossing point be found instead? Make a new drawing of the carrier densities for this situation.
    Why is it sufficient to consider the zeroth-order approximation for the charge densities in the space-charge region (*i.e.*, to just consider the constant densities of charged dopant atoms) for gaining a **generally** valid qualitative understanding?
    (If you want to be on the safe side, let the computer plot the carrier densities. For this, use the analytic solution obtained from the zeroth-order approximation for the charge

densities, giving a linearly increasing and decreasing electric field, and a quadratic function for the electrostatic potential. Use the latter to give an analytic expression for the band bending, from which analytic expressions for the carrier densities can be obtained. Then, use the computer just to plot these analytic solutions.)

41. Formula and discussion: Give the formula for the total efficiency of light generation and describe all factors involved.

42. Discussion: Why are the refractive indices of the semiconductor and its surrounding important for the optical efficiency? Which kind of refractive index arrangement might improve the optical efficiency, and why? What other basic idea(s) to improve the optical efficiency can you think of?

43. Discussion and drawing: Why is a standard p–n junction diode usually a rather bad light emitter? What device structure is a better choice for an efficient light emitter, and why? Give an explanation based on a schematic drawing of the band structure (it suffices to consider it in equilibrium): What kind of junctions have to be involved, and why?

44. Discussion and drawing: When making heterojunctions, what are the important parameters one must keep in mind? Consider the straddling case (type I) and discuss the formation of a p–n junction; describe the role of band discontinuity at the junction. Why are two different types of p–n junctions possible in this case? What is their main difference with respect to current flow under forward bias?

45. Discussion and drawing: How to make a single quantum well (SQW) using two semiconductors with different bandgaps? Draw the lateral conduction and valence band (CB and VB) diagram for a real SQW structure using AlAs and GaAs layers. Schematically, draw the resulting energy levels inside the SWQ, both for the conduction and the valence band (as they are to be expected from the particle-in-a-box model; for the latter, remember the solution to task #1).