<u>Semiconductors & Defects: Exercise 11 (01 Feb. '22)</u>

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

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

43. <u>Discussion and drawing:</u> 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. <u>Discussion and drawing:</u> When making heterojunctions, what are the important band structure 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 the band discontinuities 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. <u>Discussion and drawing:</u> 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 CB and VB energy levels inside the SQW (as they are to be expected from the particle-in-a-box model; for the latter, remember the solution to task #1).

46. <u>Discussion:</u> Download the paper "Electronic band gap of Si/SiO_2 quantum wells: Comparison of *ab initio* calculations and photoluminescence measurements" using [this link]. Figure 2 shows a series of normalized photoluminescence (PL) spectra of various Si/ SiO_2 multi quantum well (MQW) structures, recorded at low temperatures. Explain the observed dependency of the PL peak position on the well width of the MQW structure.

47. <u>Discussion:</u> Describe the concept of "modulation doping" and explain how it leads to a two-dimensional electron gas (or 2DEG, for short). What is the main reason that this 2DEG can have a high mobility? What other way(s) to obtain a 2DEG do you know of? What fundamental physical effect was observed in a 2DEG, resulting in a Nobel prize? (Hint: This effect occurs when the 2DEG is placed in a perpendicular magnetic field.)

48. <u>Discussion:</u> Download the paper "Si and Zn Co-Doped InGaN–GaN White Light-Emitting Diodes" using [this link]. Briefly review the different ways to come to a white-light-emitting device described in the introduction of this paper. Try to give an interpretation of the electroluminescence spectrum shown in Fig. 1: How can it be explained that the band edge emission peak depends so strongly on the current strength? What might be an explanation for the blue shift of the broad emission peak attributed to the donor–acceptor transition? (Remark: No relevant explanations are given in the paper itself!)

50. <u>Discussion:</u> Describe the processes of fundamental absorption, spontaneous emission, and stimulated emission; explain their role in lasers.

51. <u>Discussion:</u> Which kind of technical problem might occur if you fabricate heterostructures with semiconductors having different lattice constants? There are several possibilities to deal with this problem; name an example for what can be done about it.

(See next page for continuation)

52. Discussion: Why can't lasing be achieved in a two-level system? Why is a four-level scheme better suited for a laser than a three-level scheme?

53. Discussion: What is the direct semiconductor equivalent of an optically pumped four-level laser scheme? What would be a good device structure for an efficient electrically pumped semiconductor laser? Explain the meaning of "(population) inversion" and how to obtain it in the two aforementioned cases.

54. Calculation: Do the math for the first laser condition, i.e. show that $E_F^e - E_F^h \geq h\nu \geq E_g$ follows directly from the requirement that $R_{se} \geq R_{fa}$. (Hint: You may have a look at the very first international publication about this topic by following this link.)

55. Discussion: Explain the physics behind the first laser condition. To have continuous laser operation, however, it isn't sufficient to have this condition fulfilled – why? How is this all related to the transparency density and the gain coefficient?