CARLETON UNIVERSITY

FINAL
EXAMINATION
December 2018

DURATION: 3 HOURS

Department Name & Course Number: Electronics 4705A

Course Instructor(s): Tom Smy

AUTHORIZED MEMORANDA

CALCULATOR (Not Programmable)

Students **MUST** count the number of pages in this examination question paper **before** beginning to write, and report any discrepancy immediately to a proctor. This question paper has **15 pages.**

This examination question paper **MAY NOT** be taken from the examination room.

There are 10 questions on the exam. Attempt all questions. Note that the questions are not equally weighted.

I suggest you attempt the questions you know best first!

There are 124 marks. I think :-)

Student Name:

Student Number:

1. Basic Quantum Mechanics (12 Marks total):

   (a) (3 Marks) For an electron in an infinite potential well write down:

      i. The time independent Schrodinger's Eq. with the appropriate potential.

      ii. The appropriate boundary conditions.

      iii. Describe why quantization of electron energy occurs.

   (b) (2 marks) Sketch $\psi(x)$ for the first few energy states.

   (c) (1 Marks) Show how $\psi(x)$ would change if the potential well was finite.

Basic Quantum Mechanics:(cont.)

(d) (4 Marks) Show (draw!) a characteristic solutions for $\psi(x)$ for the case of two finite wells "side by side" separated by a small distance for:

- E is less then the well depth. (For both symmetric and antisymmetric cases.)
- E is greater then the well depth.

(e) (2 Marks) How would you characterize the"interaction" between the two wells. Specifically could it be understood using a classical description of the physics.

2. Electrons in crystals (Total Marks 10):

   When describing the electron behavior in materials we use an E versus k relationship ($E(k)$).

   (a) (1 marks) Describe what this relationship is. Specifically what are E and k.

   (b) (1 marks) What is the E(k) relationship for an electron in a single infinite well?

   (c) (1 marks) What is the E(k) relationship for perfectly free electrons?

   (d) (2 marks) Draw an E(k) relationship for free but periodic electrons? How does it differ from the perfectly free electron case?

   (e) (1 marks) Draw a characteristic E(k) relationship for electrons in a periodic potential with a barrier present.

   (f) (2 marks) For this case how does the barrier height/width effect the relationship?

   (g) (2 marks) When we have an electric field present what information about the electron behavior does the E(k) relationship give us?

(Electrons in crystals – Extra page for work.)

3. Band Structures (Total 20 Marks):

   (a) (4 Marks) Draw the E(k) band structure of:

      i. Direct band-gap semiconductor. Name a direct band-gap material.
      ii. Indirect band-gap semiconductor. Name an indirect band-gap material.
      iii. Which of these is better for optical devices? And why?
      iv. Sketch the optical absorption of the two materials as function of wavelength – clearly show how the materials are different.

Semiconductors:(cont.)

(b) (3 Marks) Sketch the band structure of an n-type semiconductor labeling all the important energies.

(c) (4 Marks) Describe the relationship of the majority carrier density (n) with respect to the temperature for an n-type material.

   i. Sketch n as function of T.
   ii. Label the important regions.
   iii. Describe the physical processes that characterize each region

Band Structures:(cont.)

(d) (3 Marks) What does the band structure of a metal, intrinsic semiconductor, and insulator look like. Draw band structures for each material.

(e) (2 marks) Describe in **words** and with respect to a semiconductor band structure:

- The Density of States of function
- The Fermi-Dirac function

(f) (4 marks) Describe how the two functions are used to obtain the electron density in a semiconductor. A sketch would be good.

4. Integrated Circuit Fabrication (Total Marks: 10)

   (a) (3 Marks) Describe the process of photolithography used in IC fabrication

   (b) (7 Marks) Describe the steps needed to create a fabricated a MOSFET gate structure with self aligned source/drain regions

5. Bipolar Junction Transistor: (Total Marks: 15)

   (a) (4 Marks) Draw the band structure of NPN transistor in equilibrium.

   (b) (5 Marks) Draw the band structure of NPN transistor in normal operation.

      i. What generally are the biases in this mode?

      ii. For an amplifier why is this mode used?

   (c) (4 Marks) Draw the band structure of NPN transistor in cutoff operation.

      i. What generally are the biases in this mode?

      ii. For what would this mode be used?

   (d) (2 Marks) What is the Early effect and how does it effect the I-V characteristics of the transistor.

6. MOSFET devices (Total Marks: 15)

   (a) (5 Marks) Describe the MOS material system, what is inversion is and how it is achieved.
   (b) (3 Marks) Draw the basic structure of a MOSFET.
   (c) (3 Marks) How do we control the flow of current in the MOSFET?
   (d) (4 Marks) When operated as an amplifier we use the MOSFET in "pinch-off".
      i. Describe the channel structure under pinch-off. (A picture would be good)
      ii. Why do use this mode of operation for an amplifier?

7. Schottky Diode: (Total Marks: 12)

   (a) (2 Marks) Draw the physical structure of a Schottky Diode for an n-type semiconductor.
   (b) (4 Marks) Draw the band structure at equilibrium and under reverse bias.
   (c) (6 Marks) Explain the operation of the device in terms of the physical currents flowing in both directions.

8. Optical Amplifier and Laser: (Total Marks: 15)

   (a) (2 Marks) What is the quantum mechanical effect that we exploit to achieve optical amplification? Define population inversion.

   (b) (3 Marks) What is "pumping" and for an optical fiber amplifier how do we achieve it?

   (c) (3 Marks) If we wish to create a laser from a optical amplifier what elements do we need to add to the device structure.

   (d) (2 Marks) Why do these elements produce "lasing"

   (e) (5 Marks) What are the two factors that determine the "color" of the laser light?

9. MEMS and Nano-structures (Total Marks: 7)

   (a) (1 Marks) What does MEMS stand for?

   (b) (2 Marks) How big are MEMS devices? Contrast this to nano-structured devices.

   (c) (2 Marks) What impact does the difference in size have on the science used to design these two categories of devices?

   (d) (2 Marks) For MEMs we often use sacrificial layers. What are they and how are they used?

10. Quantum Dots (Total Marks: 8)

    A simple nano-structured device is the semiconductor quantum dot.

    (a) (2 Marks) What is a quantum dot? How big would it be approximately?
    (b) (3 Marks) A key characteristic of such a device is that the properties of the device are size dependent. Why? How would we determine the characteristics of the device?
    (c) (3 Marks)Propose an application of quantum dots in a specific technology. Explain how the quantum nature of the dot is exploited.