UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2011/2012

January 2012

EBB 525/3 – Electronic Materials & Optical Devices

Duration : 3 hours

Please ensure that this examination paper contains TEN printed pages before you begin the examination.

This paper consists of SEVEN questions.

Instruction: Answer **FIVE** questions. If candidate answers more than five questions only the first five questions answered in the answer script would be examined.

The answers to all questions must start on a new page.

All questions must be answered in English.

1. Cuprate oxides are well-known superconducting materials. The material must however be cooled down in liquid nitrogen for superconductivity effect to be observed.

[a] Describe why superconductivity can only be achieved at low temperature from the point of view of quantum mechanics.

(30 marks)

[b] Explain how the grains in cuprate like yittrium based compound may hinder the movement of paired electrons.

(20 marks)

[c] Thin film of the compound in 1[b] can be produced to achieve high conductivity, sketch all the necessary layers needed to produce superconductor tape with high current density.

(20 marks)

[d] Compare and explain on the conductivity, strength and robustness of pure Cu, alloyed Cu and superconductor cuprate tapes to be used in transmitting electricity.

(30 marks)

2. [a] Conductivity in a semiconductor material like silicon is affected by the number and mobility of free carriers in the material. Answer the following questions.

(i) What are free carriers and describe two mechanisms in producing free carriers in intrinsic silicon.

(20 marks)

(ii) Doping is a known process to induce more free carriers in silicon, however the mobility of the free carriers are affected by the foreign atoms induced by doping, explain how this happens. Use appropriate diagrams to support you answer.

(30 marks)

[b] Thin film p and n-type ZnO were grown on SiC by physical method for the formation of light emitting diode emitting blue light, however it appears that the intensity of light produced is very low, why do you think this might happen, explains from the point of view of the surface resistivity of thin films.

(20 marks)

[c] What are the two basic mechanisms by which current flows in semiconductors? State an equation that may relate the two mechanisms and explain the physics of both of the mechanisms.

(30 marks)

3. [a] Describe the origin of conductivity in carbon nanotubes (CNTs) in terms of their chirallity.

(25 marks)

[b] With an appropriate diagram, explain how energy band diagram in silicon crystals involves hybridization. Relate this to the hybridization in CNTs.

(25 marks)

[c] Titania is a known n-type oxide semiconductor. Titania with nanostructure has been used as catalysts when illuminated with light for performing advanced oxidation process to mineralize several organic pollutants. How can this be achieved and state how nanostructured titania may add some benefits to the process?

(30 marks)

[d] Give examples of electrochromic oxides and state their applications.

(20 marks)

4. [a] Absorption coefficient of silicon for photon with wavelength of 0.6 μm is 2×10^4 cm^{-1}. Determine how much (in percentage) the incident photon energy will absorb by silicon with thickness of 1.5 μm?

(25 marks)

[b] Determine the maximum value of the energy gap (bandgap) of a semiconductor used as a photoconductor to be sensitive to yellow light (600 nm).

(25 marks)

[c] Figure 1 shows a structure of a buried heterostructure laser diode based on GaAs and AlGaAs. Propose new suitable semiconducting materials at the same structure for operation at 1.3 μm and at 1.55 μm? You can use Figure 3 as a reference.

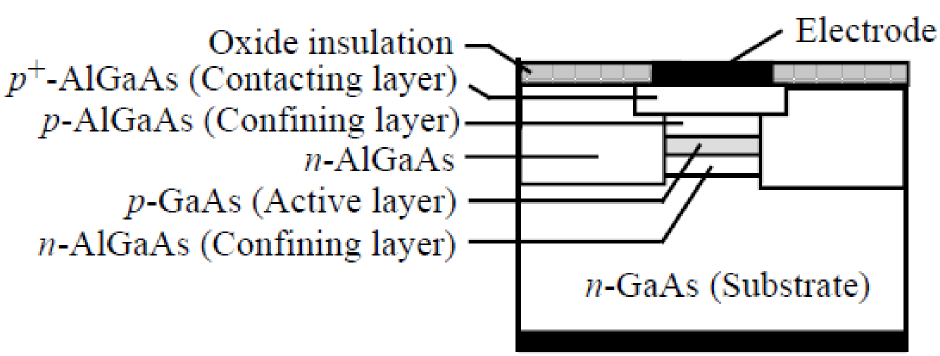

Figure 1: Schematic illustration of the crosssectional structure of a buried heterostructure laser diode.

(50 marks)

5. [a] From the known energy gap of the semiconductor GaAs (E_g = 1.42 eV), calculate the primary wavelength of photons emitted from this crystal as a result of electron-hole recombination. Is this wavelength in the visible?

(25 marks)

[b] Will a silicon photodetector be sensitive to the radiation from a GaAs laser? Why?

(25 marks)

[c] What is the thickness of a Ge and $In_{0.53}Ga_{0.47}As$ crystal layer that is needed for absorbing 90% of the incident radiation at 1.5 μm? $In_{0.53}Ga_{0.47}As$ is the InGaAs mixture that grows lattice matched to InP.

(25 marks)

[d] Consider a GaAs LED. The bandgap of GaAs at 300K is 1.42 eV, which changes (decreases) with temperature as $dE_g/dT = -4.5 \times 10^{-4}$ eV K^{-1}. What is the change in the emitted wavelength if the temperature change is 10ºC?

(25 marks)

6. [a] Suppose you are assigned to build (i) blue and (ii) green LEDs, using $Al_xGa_{1-x}N$ or $In_xGa_{1-x}N$ alloys. Calculate possible compositions for each material. Assume that $h\nu = E_g$ and use the data given in Figure 2. (Please don't use band gap data from other references!).

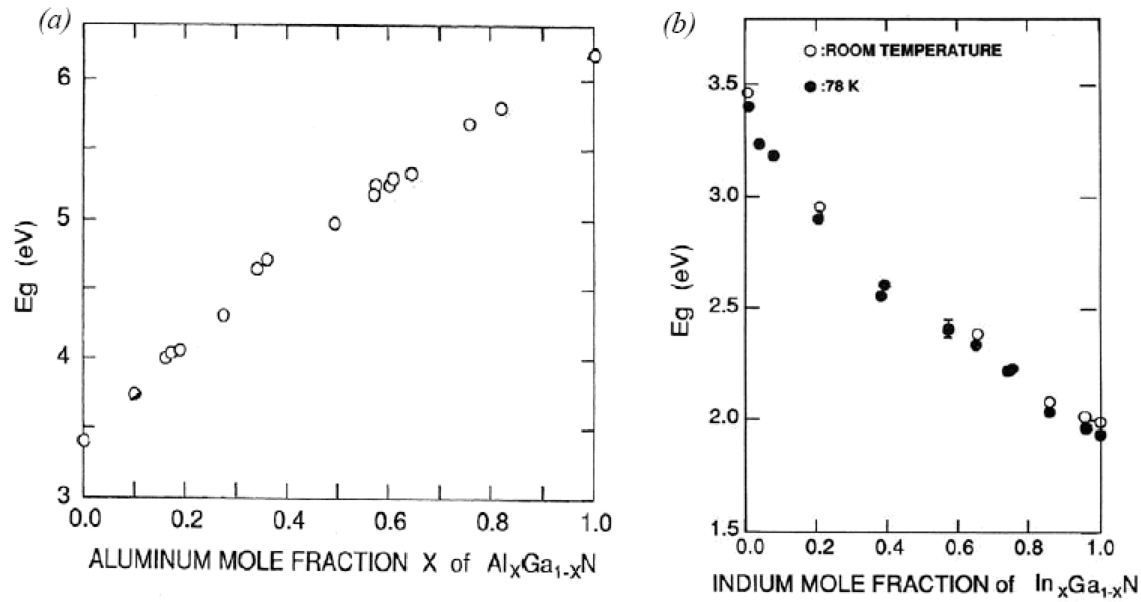

Figure 2: Bandgap versus mole fraction of aluminum in $Al_xGa_{1-x}N$ and indium in $In_xGa_{1-x}N$

(50 marks)

[b] Consider the design of a “white” LED. You will recall that “white” light is actually the combination of all visible colors, and can be effectively modeled by the simultaneous presence of red, green, and blue (RGB). Red light has a wavelength of approximately 650 nm, green light is approximately 530 nm, and blue light is approximately 430 nm. Two design approaches are available for white light emission. One is to build three small, discrete devices (red, green, and blue), package them within a single LED package, and operate them simultaneously to yield the white light. The other is to create a single structure that simultaneously generates photons over the visible spectrum.

(i) Discuss the pros and cons of these two approaches, and comment on the what materials you should use in each case.

(ii) Where possible, explain your selections in terms of output wavelength, efficiency, substrate availability, and reliability, and in the second case, be clear about how a single device can be expected to simultaneously produce a series of different wavelengths throughout the visible region. Be specific in your discussions. You may neglect issues such as how the discrete devices are actually mounted and how they electrically connected.

(50 marks)

7. [a] Based on the data in Figure 3, design a semiconductor laser to operate at 980 nm. In your answer consider the following:

   (i) What substrate, core and cladding material to use? If there are several possible combinations, which would you choose?

   (ii) What will the band structure look like? Draw it as accurately as you can, including the effect of doping, for the unbiased case.

   (iii) What factors affect the spectral output of the laser? Illustrate your answer with a sketch of how you expect the intensity of the output light to depend on wavelength (or frequency).

   (iv) What other materials data would you like to have in order to complete your laser design, and why?

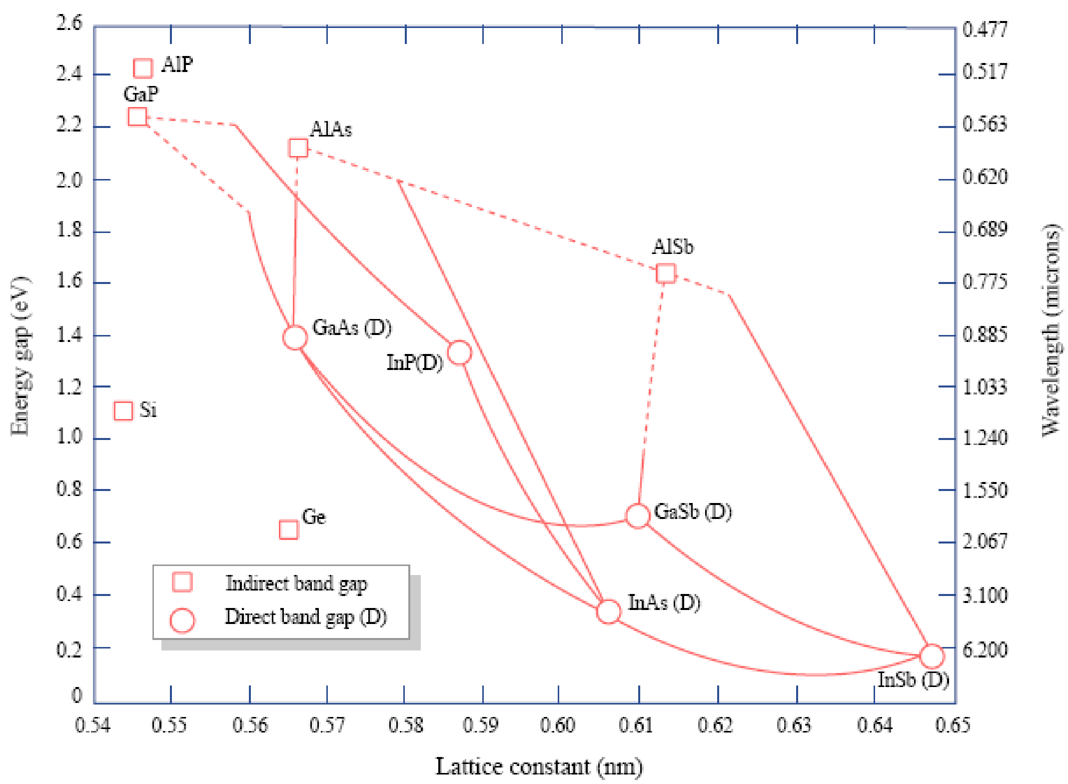

Figure 3: Energy bandgap and lattice constant of various semiconductor materials

(50 marks)

[b] (i) A photovoltaic cell has a value of $I_o = 10^{-6}$ A and $I_g = -2$A. Its internal resistance is 0.1 ohm. Estimate the best choice of load resistance in order to get the most power out of the cell, and what the maximum power is. (You do not have to calculate it exactly).

(ii) Why is the maximum efficiency of a Si solar cell only about 30%? Give at least 3 reasons.

(50 marks)

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