Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (2.0 hours)

EEE6216 Energy Efficient Semiconductor Devices

The paper is comprised of part A and part B.

Answer <u>all</u> the part A questions. This section totals to 40 marks

Answer <u>any two</u> part B questions. Each question is worth 20 marks.

No marks will be awarded for solutions to a third question in part B.

Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

PART A (short questions)

*Answer **all** questions*

A. 1. Explain the role of greenhouse gases in global warming. What is the most significant greenhouse gas and where does it originate? **(2)**

2. What is meant by the term 'Air Mass', when used in photovoltaics. Explain why AM1.5 is used widely when characterising solar panels. **(2)**

3. The external quantum efficiency of an LED is given as $\eta_{EQE} = \eta_{inj}\ \eta_{int}\ \eta_{ex}$,where η_{inj} is the injection efficiency, η_{int} is the internal quantum efficiency and η_{ex} is the extraction efficiency. Define and explain each of these three efficiency components. **(3)**

4. Why is it inappropriate to use the irradiance (power density) in W/m^2 when recording the 'brightness' of room lights? Which unit is more appropriate? What links these two units? **(2)**

5. What is a meant by the term Photonic Integrated Circuit (PIC)? Describe the advantages of this approach. **(2)**

6. What is the main factor which determines the power ceiling for processors within (i) a desktop computer and (ii) a smartphone? What would be typical values for modern devices? **(2)**

7. Explain how modern VA and IPS LCD panels differ in construction from the basic Twisted Nematic Liquid Crystal display. What are the advantages and disadvantages of these approaches? **(3)**

8. A 3-junction semiconductor solar cell comprises Ge (Eg=0.7eV), GaAs (Eg=1.42eV), GaInP (Eg=1.8eV). Which material would be used for the top cell, the middle cell and the bottom cell? Why choose this arrangement? **(2)**

9. Explain how sunlight and a semiconductor photo-catalyst can be used to generate hydrogen from water. Which two must occur for water to be photo-electrochemically split in this system? **(3)**

10. What is meant by the terms static and multiplexed when referring to the connection of LCD pixels? If a HD LCD display has 1024 x 768 pixels, calculate the number of connections required in both cases. Why do large pixel numbers require active multiplexing? **(3)**

11. The light-sensitive region of the human retina contains two types of photoreceptor cells. What are these cells and what are the main differences between them? The minimum pitch of these photoreceptors is found to be approximately 2 µm. If a genetic mutation led to a 'super-human eye' with a pitch of 0.2 µm would this give improved spatial resolution? **(2)**

12. For a GaN based LED with radiative lifetime τ_{rad} = 5 ns and non-radiative lifetime τ_{non} = 2 ns calculate the internal quantum efficiency of the device. Briefly describe the radiative and non-radiative recombination processes and how the internal quantum efficiency of the device could be increased. **(4)**

13. What is the typical efficiency value we might expect from a good commercially available crystalline solar cell and how might this be improved further at the manufacturing stage? **(2)**

14. Explain two methods that can be used to produce a full colour display using a micromirror-based spatial light modulator **(2)**

15. How could a global foundry model for PICs lead to a reduction in the required global energy generation **(2)**

16. Sketch the band structure of a bi-layer OLED device, including the emissive layer and electron blocking material. Indicate clearly the relative HOMO/LUMO positions of each material. Explain why the efficiency of this Bi-layer OLED is increased compared to a single layer OLED device. **(4)**

PART B (long questions)

*Answer any two questions **only***

1. You are provided with a photovoltaic module comprising 72 identical crystalline silicon solar cells connected in series. The module specifications (at a temperature of 25˚ C and under AM1.5 illumination condition and 1kW/m^2 irradiance) state that the open circuit voltage is 48.8V and the short circuit current is 6.43A.

(i) What is the open circuit voltage and short circuit current of each cell that makes up this module? **(2)**

(ii) What is the voltage and current of this module when producing maximum power? **(10)**

(iii) What is the maximum power this module can produce? **(1)**

(iv) What is the fill factor of the cells making up this module? **(2)**

(v) The efficiency of the module is known to be 20%. What is the approximate size of each of the individual solar cells making up the module? **(3)**

(vi) As the module is exposed to sunlight, its temperature increases to 50˚ C. Explain qualitatively what happens to the module performance and why. **(2)**

2. An LED device is operating in air, the device is made of GaN and the electrical contact on the top surface can be ignored.

(i) Calculate the critical angle for light emitted from the surface of the GaN into air assuming $n_{GaN} = 2.4$ and $n_{air} = 1$. Recall that $n_1 \sin\theta_1 = n_2 \sin\theta_2$ **(4)**

(ii) Taking into account reflection losses, but ignoring absorption losses, calculate the extraction efficiency of the device for first pass light (i.e. ignoring multiple reflections). You are reminded that the fraction of emitted light from the surface is defined by $I = \frac{1}{4}\left(\frac{n_2}{n_1}\right)^2$ and reflection is given by $R = \left(\frac{n_2-n_1}{n_2+n_1}\right)^2$ **(4)**

(iii) A large epoxy dome is used with a hemispherical surface with the top surface of the LED at the centre of the dome. The refractive index of the epoxy is $n_{epoxy} = 1.5$. Assuming no other materials are added, calculate the extraction efficiency of the device and explain any assumptions the geometry of the epoxy lens allows you to make. **(6)**

(iv) Identify and describe two techniques, other than producing a hemispherical surface, for increasing extraction efficiency of an LED device. Sketch simple diagrams to indicate how the techniques work. **(6)**

3. (i) The total power consumed by a microprocessor is a sum of the dynamic and static power dissipation. List the main elements of each of these components and describe their origin. **(3)**

(ii) A state of the art integrated circuit has 1 billion gates and operates at clock speed of 2.66GHz. The CMOS gates have a load capacitance of 5.6×10^{-15}F, a gate leakage current (I_{leak}) of 5nA and a threshold voltage (V_T) of 0.12V. The supply voltage needs to be a minimum of twice the threshold voltage.

Assuming only the switching action and gate leakage are important, calculate the minimum power dissipation of the IC at rest and during operation with an activity factor of 0.2. **(6)**

(iii) If we attempt to reduce dynamic power dissipation through a reduction in device size (scaling), what would be the likely consequences for V_T and for the gate leakage current (I_{leak})? **(4)**

(iv) Describe how a modern microprocessor will limit its power dissipation depending on system demands and external factors. What are the limitations of this **(3)**

approach?

(v) What are the major advantages of LED backlit displays compared to cold cathode fluorescent lamps? Consider both the power consumption and visual quality of the display. Apart from the display and processor, what other elements of a typical notebook computer contribute to significant power losses? **(4)**

4. A widely tuneable laser is essentially a low component count monolithically integrated Photonic Integrated Circuit (PIC) frequently found in telecoms transponder modules.

(i). Draw and label a schematic diagram showing the sections that comprise a SG-DBR laser. **(4)**

(ii) Describe the operation of the SG-DBR, using diagrams to outline the role of the Vernier effect and the role of the sampled grating. **(6)**

An SG-DBR laser is designed for operation about a central wavelength of 1060nm with a possible tuning range of 95nm, as defined by the FWHM of the envelope of modes. The design incorporates 400μm long sampled grating sections with sampling periods 20 and 22μm respectively for front and rear gratings. For this design determine:

(iii) What should the burst length be, assuming n_g = 3.5 and that the envelope FWHM can be approximated by $\Delta\lambda \sim \frac{1.88\lambda^2}{\pi n_g d}$. **(2)**

(iv) What should the period of each grating burst be, assuming n_{eff} = 3.3? **(2)**

(iv) Describe, with the aid of sketches, how impurity-free vacancy-induced disordering can provide a scheme for active-passive integration in monolithically integrated PICs. Explain its relative advantages over butt-joint regrowth. **(6)**

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