ENGINEERING TRIPOS IIB

Friday 24 April 2009 9 to 10.30

Module 4B18

ADVANCED ELECTRONIC DEVICES

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1 (a) Describe how one would make a capacitor of 10^{-18}F from a multilayer structure consisting of n-doped GaAs on either side of an undoped layer of AlAs that is 10 nm thick. State any approximations that you make. [Assume $\varepsilon_{AlAs} = 10^{-10}$ Fm^{-1}] [20%]

(b) How would you confirm that you had made a capacitor of 10^{-18} F? [20%]

(c) If one were to make an array of thousands of such capacitors, comment on the reproducibility of the capacitances. [20%]

(d) What voltage is needed to put 1, 2 and 3 electrons on the capacitor plates? [20%]

(e) If instead we make columns from a multilayer structure of undoped AlAs-GaAs-AlAs each AlAs layer being 4 nm thick and the GaAs layer being 10 nm, which is itself sandwiched between layers of heavily doped GaAs, describe the processes by which electrons get through the device regarded as a diode. [Recall that the quantum confinement energy, in millielectron volts for a quantum well of width λ is given by $E=5000/(\lambda^2)$ meV. In addition the thermal energy of an electron at a temperature of 300 K is 25 meV.] [20%]

2 (a) Explain the meaning of each term in the two expressions below, and derive the first and second Johnson criteria that place materials limits on the performance of a transit time semiconductor device, and comment on their significance for device design.

1st: $V_M f_T = E_B v_s / 2\pi$,

2nd: $PZ(f_T)^2 = (E_B v_s)^2 / 32\pi^2$.

[40%]

(b) If the best Gunn diodes in GaAs are capable of delivering ~0.50W output power at 35GHz what might be expected from GaN Gunn diodes if the ratio $(E_B v_s)_{GaAs} / (E_B v_s)_{GaN} = 0.2$? In practice, what might limit the performance of such a Gunn diode? [20%]

(c) Explain the role of a GaAs/AlGaAs heterojunction in improving the performance of a GaAs Gunn diode, with reference to frequency, output power and efficiency, noise levels and temperature sensitivity. [40%]

3 (a) Describe the basic dc current-voltage characteristic required of a diode so that it might operate as

(i) a detector or mixer
(ii) a source

of microwaves. [20%]

(b) Using tunnelling through thin semiconductor layers as the basis for designing the current-voltage characteristics, describe the multilayer semiconductor structure needed to generate each of the above devices if they are to operate at (say) 100GHz. [20%]

(c) Describe how one checks that the multilayers as grown by epitaxy, are in fact of the thickness and doping level that one asked for. [20%]

(d) Describe the advantages and disadvantages of using tunnel barriers as a design element of semiconductor devices in terms of device performance, yield, uniformity, reproducibility etc. [20%]

(e) What other ways are there of generating the dc current-voltage characteristics for a detector diode? [20%]

4 Write an essay on the end of Moore's law. Describe what is contributing to the end. Discuss various options for going beyond Moore's law, and comment on the potential for commercial success of these various options. [100%]

5 (a) Describe the advantages and disadvantages of field effect and bipolar devices for computation. [25%]

(b) Describe how heterojunction field effect transistors and heterojunction bipolar transistors exploit the physics of heterojunctions to achieve superior performance. [25%]

(c) Why has GaAs had a place in microelectronics in direct competition with silicon? [25%]

(d) Illustrate the further advances of the use of heterojunctions as one moves from a simple GaAs system to ones that use the GaAs/AlGaAs and the InGaAs/AlInAs heterojunctions in field effect transistors. [25%]

END OF PAPER