EGT3
ENGINEERING TRIPOS PART IIB

Monday 11 May 2026   9.30 to 11.10

Module 4B2

POWER MICROELECTRONICS

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.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

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

You may not remove any stationery from the Examination Room.

1 (a) Explain the consequences on the electrical characteristics of increasing or decreasing the thickness of the AlGaN layer in a Gallium Nitride High Electron Mobility transistor (HEMT) while keeping constant all the other parameters. [20%]

(b) An Insulated Gate Bipolar Transistor (IGBT) used in a power electronics application has current waveforms as shown schematically in Fig. 1. During the on-state period, the current increases linearly with time reaching a peak value, I_{peak} = 100 A from where the device switches off to an off-state voltage, V_{off} = 3 kV. The IGBT operates at a frequency of 50 kHz with a duty cycle, D = 50%. The turn-off energy loss per switching cycle is estimated to be 3 mJ while the turn-on and off-state losses can be neglected.

For a first order approximation, the on-state voltage drop in the IGBT is estimated to vary linearly with the on-state current as shown in equation (1):

$$V_{on} = V_{offset} + R\, I_{on} \tag{1}$$

where V_{offset} = 2.5 V and R = 10 mΩ.

(i) Draw the current and voltage waveforms on the same graph and estimate the on-state power losses in the IGBT. [50%]

(ii) Estimate the switching power losses, and given the result, comment on the choice of the operating frequency for the IGBT. [15%]

(iii) Given equation (1) what could be the material employed in making the IGBT? Equation (1) is only an approximation and can lead to significant errors. Explain why this might be the case. [15%]

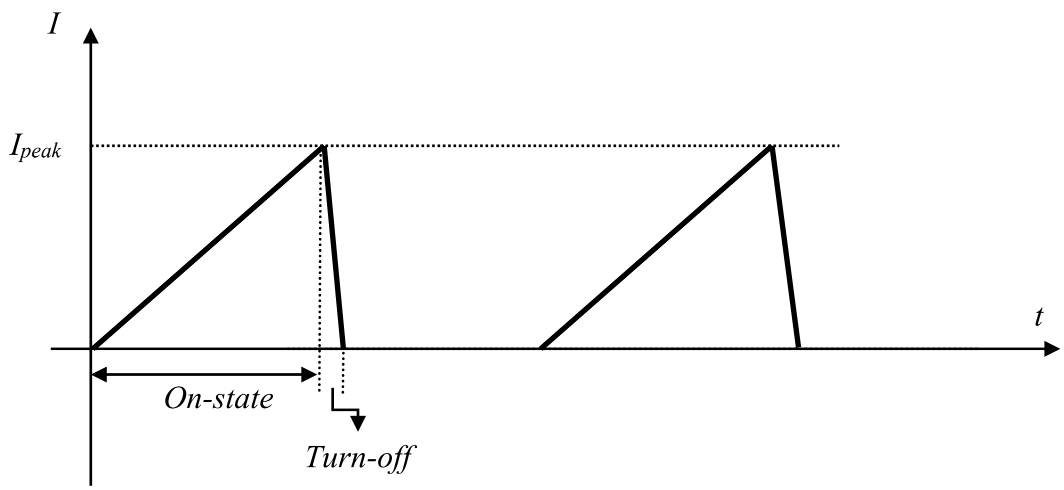

Fig. 1

2 (a) Draw a cross-section of a trench Silicon Carbide power MOSFET using a p+ shield region under the insulated gate. Briefly explain how the p+ shield influences the performance of the device in on-state, off-state, turn-on and turn-off states. [35%]

(b) Fig. 2 shows the protection circuits (Sensing and Protection – S/P) for a smart Insulated Gate Bipolar Transistor (IGBT).

(i) Explain the operation of each of the over-voltage S/P, over-current S/P and over-temperature S/P circuits. Describe the role of each of the components within the circuits. [50%]

(ii) Explain the design considerations of the Sense IGBT and outline possible issues with the current sensing for the Sense IGBT. [15%]

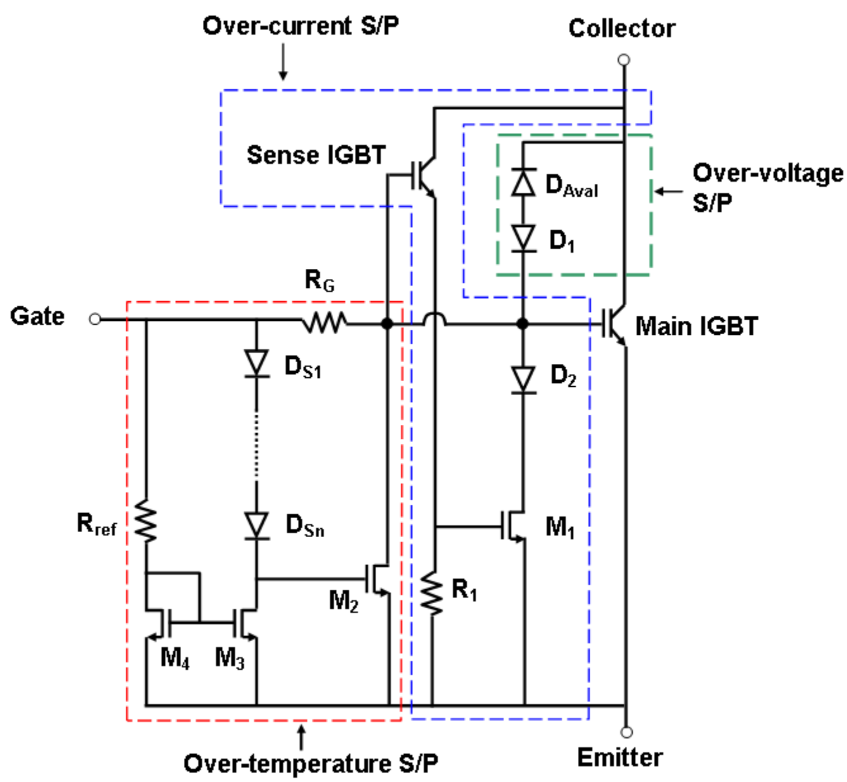

Fig. 2

3 The cell structure in Fig. 3 is part of a power High Electron Mobility Transistor (HEMT) in GaN technology. The device has three main terminals, Source (S), Drain (D), Gate (G) and uses a Silicon substrate connected to a fourth terminal (Sub).

(a) Show specifically the position of the piezo-polarization charges and make an argument whether the device is normally-on or normally-off. Explain its operation during on-state, off-state, turn-on and turn-off. [55%]

(b) Give one advantage and two disadvantages of this device compared to a classical power HEMT in GaN technology. [15%]

(c) What would be an appropriate connection for the Sub terminal? Briefly explain the advantages and disadvantages of changing the silicon substrate to a silicon carbide substrate. [15%]

(d) Describe the operational consequences if the p-GaN gate were to be changed to a Schottky metal gate in direct contact to the top AlGaN layer. [15%]

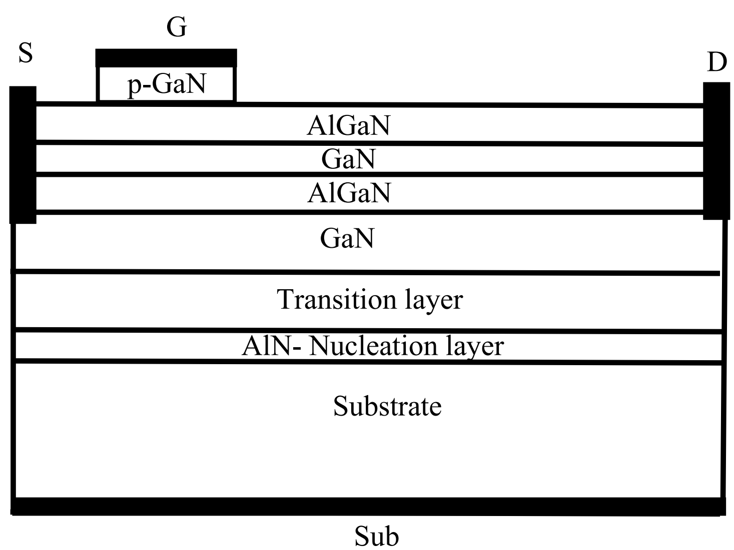

Fig. 3

4 (a) Explain the edge effect in high voltage devices and describe two termination techniques that can be used to reduce this effect. [35%]

(b) Explain why a field ring termination design with equal spacing between the field rings is not efficient in terms of termination breakdown voltage per unit area. Briefly describe how the distance between the field rings should be varied for a higher breakdown voltage per unit area. [20%]

(c) Draw schematically a cross section of a lateral REduced SURface Field (RESURF) Power MOSFET. Explain why this structure has been successfully made of silicon but not of silicon carbide or gallium nitride. [25%]

(d) Give two key advantages and one key disadvantage of a Gallium Nitride High Electron Mobility Transistor (HEMT) over a Silicon Carbide Power MOSFET for 600 V voltage rating. How would you expect this to change if the voltage rating were to be increased to 1.5 kV? [20%]

END OF PAPER