Version FU/2

EGT3
ENGINEERING TRIPOS PART IIB

Monday 23 April 2018 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.

1 (a) Discuss the role of charge balance in a superjunction MOSFET. Draw schematically a graph showing the breakdown voltage as a function of charge imbalance between the n-pillar and p-pillar as a percentage. [30%]

(b) An Insulated Gate Bipolar Transistor (IGBT) used in a Switch Mode Power Supply (SMPS) 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} = 16 A from where the device switches off. 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 eq. (1)

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

where V_{offset} =1.5 V and R = 0.5 Ω.

(i) Estimate the on-state power losses in the IGBT. [30%]

(ii) Estimate the switching power losses, and given the result, comment on the choice of the operating frequency for the IGBT. [20%]

(iii) For accurate modelling of a real IGBT, eq (1) leads to significant errors. Explain why this might be the case and discuss the impact of its use in the power loss estimation. [20%]

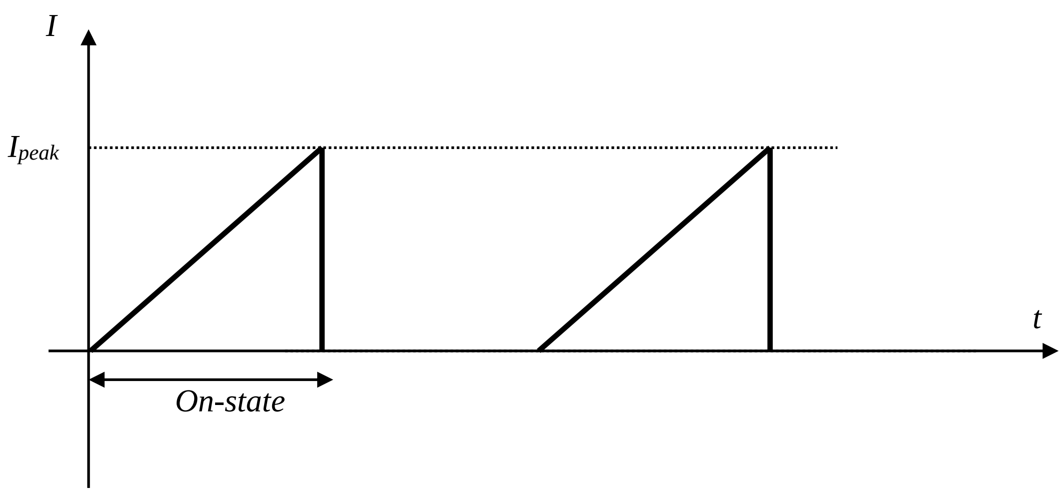

Fig. 1

2 (a) Draw a cross-section of an Insulated Gate Bipolar Transistor (IGBT) and show on the cross-section the equivalent circuit components of the MOSFET, the bipolar transistor and the PIN diode. Describe briefly the role and operation of each of these components. [30%]

(b) Fig. 2 shows the protection circuits (Sensing and Protection – S/P) for a smart 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. [20%]

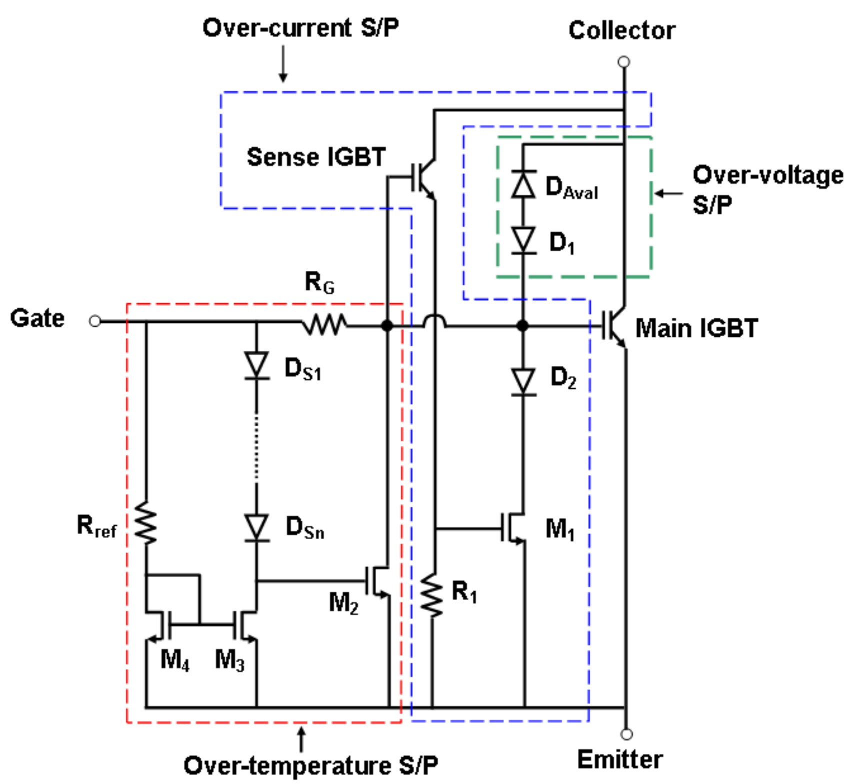

Fig. 2

3 The cell structure in Fig. 3 is part of a vertical power device. The device features three terminals (Terminal 1, Terminal 2 and Terminal 3).

(a) Explain its operation during on-state, off-state, turn-on and turn-off. [60%]

(b) Give one advantage and two disadvantages of this device compared to a Junction Field Effect Transistor (JFET). [20%]

(c) Describe the operational consequences if the p-well doped layer were to be changed to an n-type doped layer. [20%]

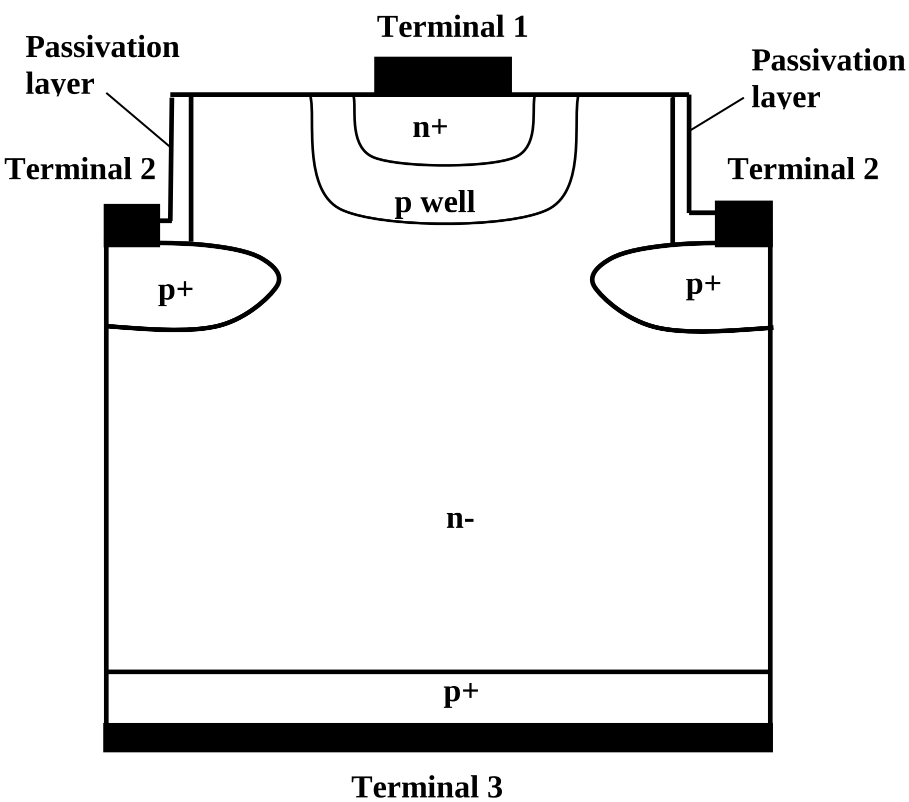

Fig. 3

4 (a) Explain the edge effect in high voltage devices and describe two termination techniques to reduce these effects. [40%]

(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 should be varied for a higher breakdown voltage per unit area. [20%]

(c) Draw a Gallium-Nitride High Electron Mobility Transistor (GaN HEMT) and explain all the operational consequences (and the associated trade-offs) of increasing or reducing the distance between the gate and the drain terminals in the GaN HEMT. [20%]

(d) Give two advantages and two disadvantages of a GaN HEMT over a silicon power MOSFET for the same voltage range, 600V to 1.2 kV. [20%]

END OF PAPER

ENGINEERING TRIPOS PART IIB 2018
4B2 Numerical Solutions

Q1: On-state losses: 27.33W
Turn-on Losses: 150 W