ENGINEERING TRIPOS PART IIB

Wednesday 26 April 2006 9am to 10.30am

Module 4B2

POWER ELECTRONICS AND APPLICATIONS

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) The circuit in Fig. 1 shows a simplified inductive switching circuit for a high voltage system such as a Switch Mode Power Supply (SMPS),

Assuming that the switch is ideal, draw the current and voltage waveforms of the PIN diode, D_f, as a function of time, during on-state, turn-off and off-state. Explain the significance of the distinctive time intervals during the turn-off. [30%]

(b) Assume now that the switch is not ideal and its waveforms are as shown in Fig. 2. The switch operates at a switching frequency of 100 kHz with a duty cycle D = 50%. The other parameters are: V_{dc} = 400 V, the off-state leakage current I_{OFF} can be neglected (I_{OFF} =0) the on-state current I_{ON} = 1 A, the on-state voltage V_{ON} = 3V, the turn-on delay time t_d = 0.1 μs, the rise time t_r = 0.2 μs, the turn-off delay time t_s = 0.1 μs, the turn-off voltage growth time t_g = 0.3 μs, the fast current fall time t_{f1} = 0.1 μs and the slow current fall time t_{f2} = 0.5 μs. Assume the current at the end of the fast current fall is I_h = 0.3 A.

(i) What device is likely to have the waveforms shown in Fig. 2? Justify your choice. What is the significance of the current I_h ? [20%]

(ii) Estimate the static, switching and total power losses in the switch. [50%]

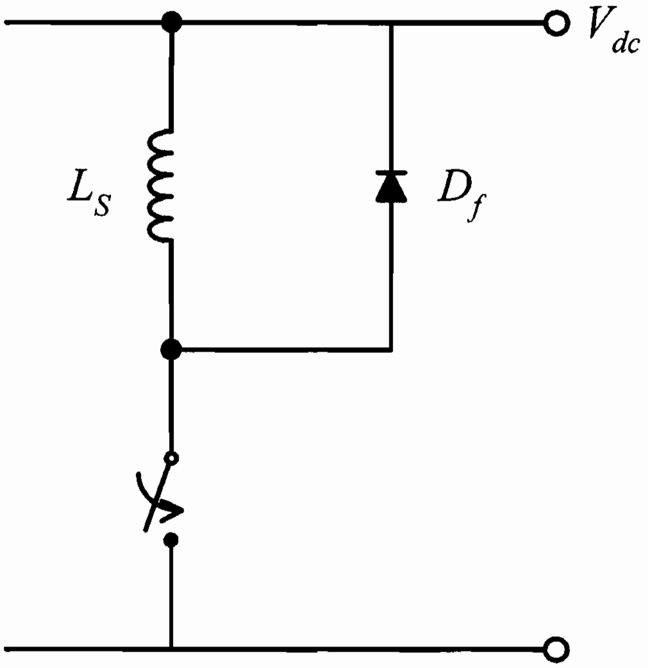

Fig. 1

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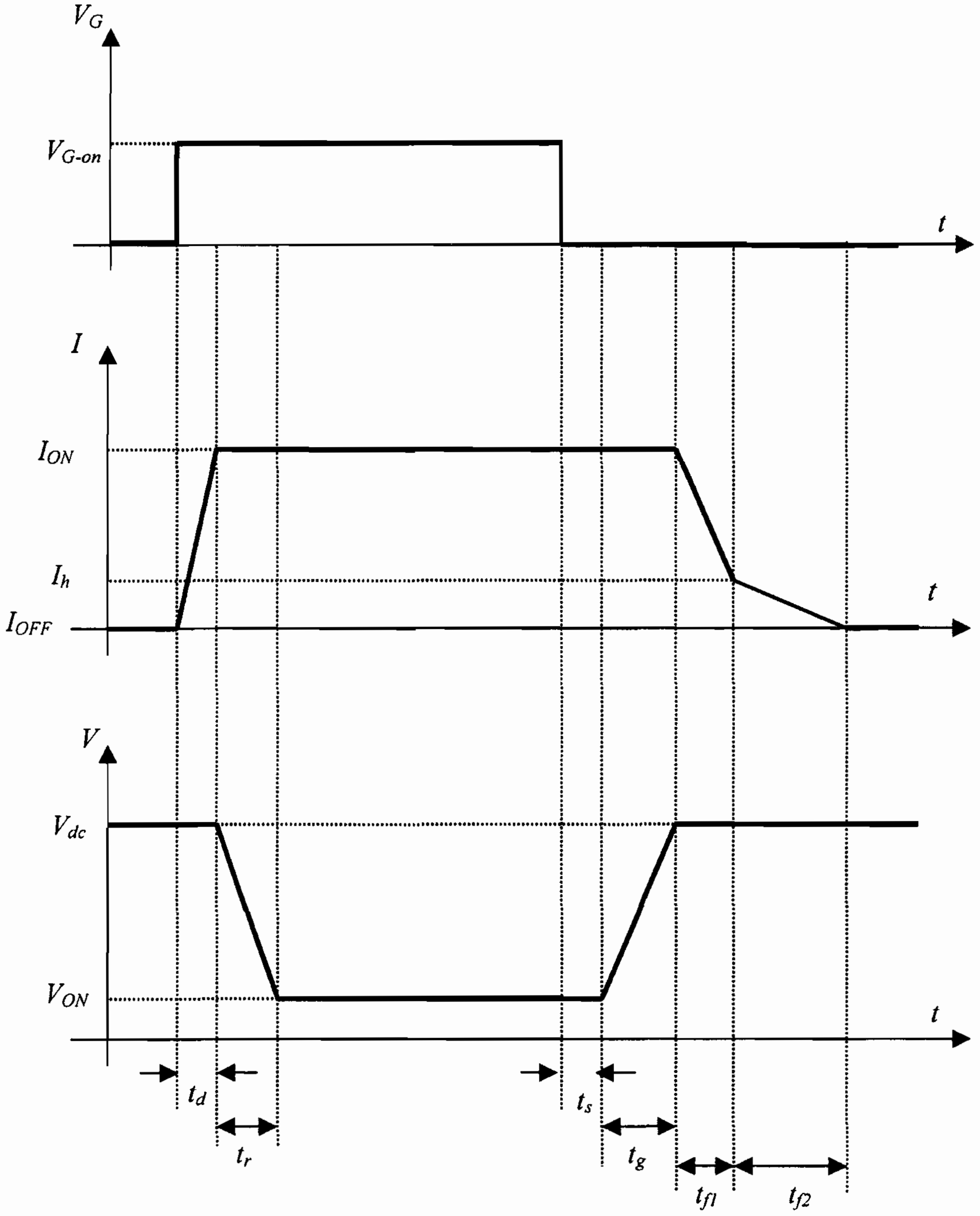


Fig. 2

(TURN OVER

2. (a) Explain the edge and curvature effects in high voltage devices and briefly describe one termination technique to reduce these effects. [30%]

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 efficiency. [20%]

(b) The Non-Punch-Through (NPT) power diode shown in Fig. 3 has the drift region split into two regions with different doping concentrations N_1 and N_2. The width of the first region is d, and assume that the second region is sufficiently long so that the diode remains in non-punch-through state at breakdown.

(i) Sketch the electric field distribution as a function of the distance, across the diode and calculate the breakdown voltage as a function of the doping concentrations N_1 and N_2, the width d and the critical electric field in the semiconductor. [30%]

(ii) Analyse the breakdown voltage if $N_1 = N_2$, $N_1 > N_2$ and $N_1 < N_2$. [10%]

(iii) If N_2 and d are fixed, find the optimal doping concentration N_1 to yield maximum breakdown voltage. [10%]

You may assume the following equation in an abrupt one-dimensional p+/n-junction:

$$w = \left[\frac{2\varepsilon_r \varepsilon_0 V}{q} \frac{1}{N_D} \right]^{\frac{1}{2}}$$

where w is the depletion region width; N_D is the doping concentration of the n- side of the junction, V is the reverse voltage and the other symbols have their usual meaning.

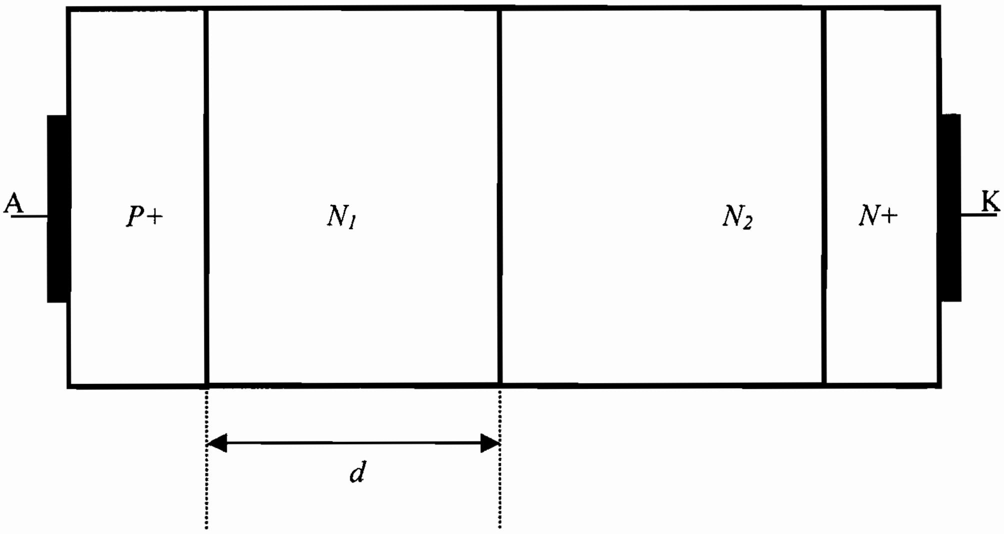


Fig. 3

3. (a) Describe the operation of a bipolar junction transistor (BJT) and that of a power MOSFET in the saturation region of the on-state. Highlight the differences in the significance of saturation in bipolar and unipolar structures. [30%]

(b) An n-channel, punch-through (PT), anode shorted, vertical IGBT has an equivalent short resistance (i.e. the resistance that appears in parallel with the base-emitter junction of the pnp transistor) of 10 Ω. The doping resistance of the drift layer, which includes the spreading resistance from the accumulation layer, is 50 Ω. The channel and accumulation layer resistances are 20 Ω. The effective gate voltage $V_G - V_T = 10$ V.

(i) Draw the cross-section of the anode-shorted IGBT, its equivalent circuit and its typical I-V on-state characteristics. [40%]

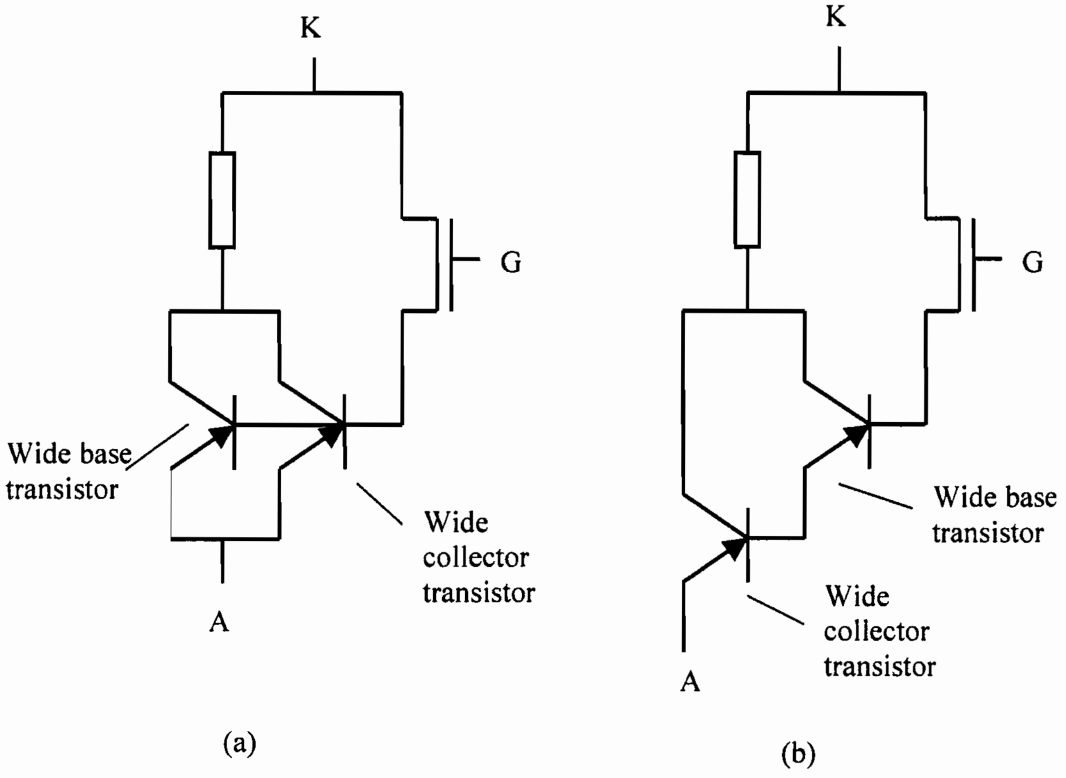
(ii) Find the snap-back voltage and current, where the device changes from a unipolar mode into a bipolar mode. State any assumptions made. [30%]

4. (a) Explain all the operational consequences and the associated trade-offs of increasing or reducing the n-buffer doping in a punch-through (PT) Insulated Gate Bipolar Transistor (IGBT). [20%]

(b) Fig. 4 shows the equivalent circuits of two lateral MOS-bipolar devices. Explain briefly their operation and draw their static I-V characteristics highlighting the differences between the two structures. [30%]

Draw the cross-section of the two structures corresponding to the equivalent circuits shown in Fig. 4 (a) and (b). Note that the second circuit describes a novel structure. [30%]

Comment on the performance of the two structures and their drawback when compared to a lateral Silicon-on-Insulator (SOI) Insulated Gate Bipolar Transistor (LIGBT). [20%]



(a) (b)

Fig. 4

5. (a) Describe the body diode structure and its operation in a power MOSFET. [20%]

Explain why the standard Insulated Gate Bipolar Transistor (IGBT) does not feature a body diode. Explain how a body diode can be incorporated in an IGBT by changing the anode structure. Show a cross section of such a device and briefly compare its performance to a standard IGBT. [30%]

(b) Highlight the differences between a symmetrical and an asymmetrical thyristor. Draw schematically the static I-V characteristics of a symmetrical thyristor and describe the main regions/parameters associated with them. [30%]

(c) Draw schematically the turn-on waveforms of a thyristor indicating the main time domains and their significance. [20%]

END OF PAPER

Answers 4B2 – 2006.

Q1. (b) P_{ON}=1.41W, P_{OFF}=0, $P_{turn\text{-}on}$=6.03W, $P_{turn\text{-}off}$=11.68W, P_{total}=19.12W

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Q3 (b) (ii) $I_{Snap\text{-}back}$=70mA, $V_{Snap\text{-}back}$=5.6 V