ENGINEERING TRIPOS PART IIB

Wednesday 21 April 2004 9 to 10.30

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.

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

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1 (a) Explain carefully the importance of *conductivity modulation* in high voltage power semiconductor devices. Explain briefly how this arises in an IGBT. Illustrate your answer with an appropriate sketch of the mobile carrier distribution. [40%]

(b) Describe the use of buffer layers in power semiconductor devices, making reference to sketches of both electrostatic field and voltage distributions in your answer. [30%]

(c) Describe briefly the mechanisms related to the formation of tail currents in IGBTs and GTOs and suggest two methods by which tail currents may be minimised. [30%]

2 (a) Derive an expression for the anode current of a conventional thyristor in terms of the constituent transistor common base current gains, α_{npn} and α_{pnp}. Describe carefully the turn on process in a thyristor. Hence, explain why snubbers are commonly used in thyristor circuits. [40%]

(b) Experimental thyristor turn-off waveforms are shown in Fig. 1. The reverse recovery voltage waveform in Fig. 1 may be approximated by

$$V_{AK} = 3500 \sin(\omega t) ,$$

where the sine period is 200 μs . Assume the current returns to zero linearly in the half period of the voltage waveform. Hence calculate the turn off losses in the thyristor at 50 Hz . [30%]

A snubber arrangement including a turn off snubber is shown in Fig. 2(a). For an initial design, assume the thyristor reverse recovery current is unchanged and the effects of the saturable turn-on snubber and the small R-C snubber can be neglected. The revised subcircuit for the thyristor turn off is shown in Fig. 2(b), where the supply inductance is 100 μH. Choose a value for the capacitor *C*, so that the voltage across *C* has just risen to the supply voltage when the thyristor current has fallen to zero.

Hence explain why turn-off snubbers are rarely used in thyristor circuits. [30%]

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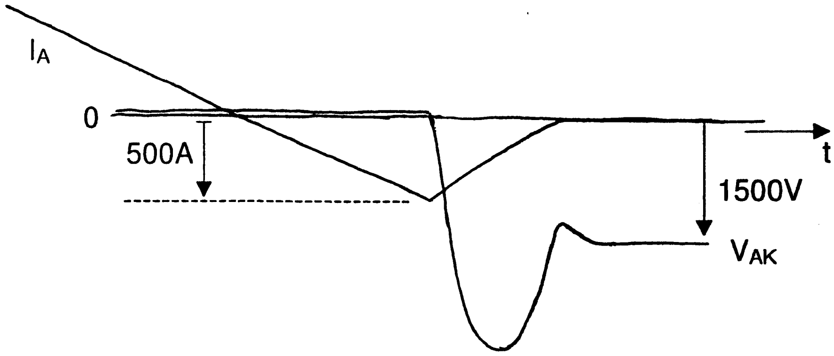

Fig. 1

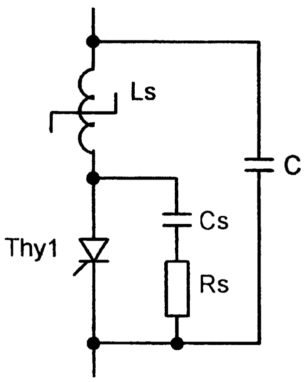

Fig. 2(a)

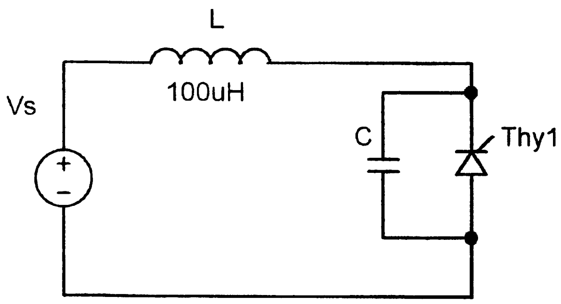

Fig. 2(b)

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3 (a) Carefully describe the operation of the MOS channel within a planar IGBT. Explain the design of the p-well and account for the short circuit safe operating area of high current IGBTs. [40%]

(b) The IGBT of (a) is to be used with closed loop voltage control, as shown in Fig. 3, with an ideal op-amp with gain A and ideal feedback voltage fraction α. The gate resistor R_G provides stability in the closed loop system by forming a low pass filter with the IGBT input capacitance. By considering the characteristics of the IGBT, explain why this is an unattractive method of stabilising the performance. [20%]

An improved design incorporates an additional dv/dt feedback term with the voltage feedback. By analysing the small signal behaviour of the revised circuit and using the small signal equivalent circuit for the IGBT shown in Fig. 4, show that the dv/dt feedback may be used to increase the damping of the second order system. Assume that the load and stray inductance seen at the collector is a pure current source and may be neglected in the small signal analysis. Also assume that the component of the collector current associated with C_{GC} may be neglected. [40%]

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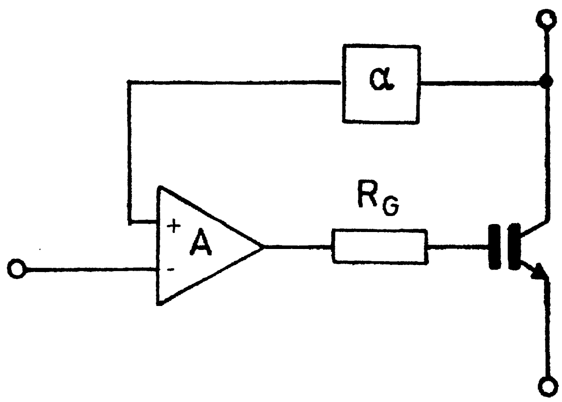

Fig. 3

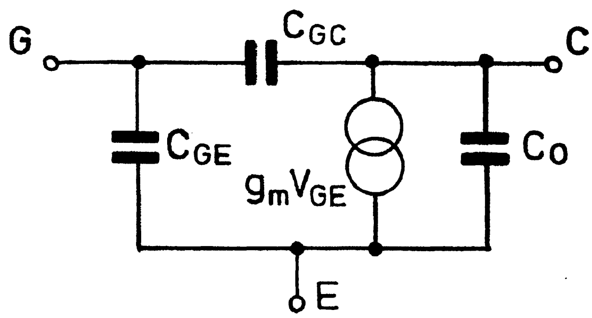

Fig. 4

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4 (a) Carefully sketch and label a typical guard ring structure for edge termination of a high voltage discrete MOSFET. Hence or otherwise describe the features of a typical high voltage MOSFET, paying particular attention to the off state. [50%]

(b) Fig. 5 shows a novel thyristor device which has turn off capability. Note that it includes a floating ohmic contact (FOC), which is able to absorb hole and electron currents, depending on the semiconductor type to which it is attached. Draw an equivalent circuit of this device for the on-state showing the connections between the component transistors. Clearly label the conducting MOS channel.

Hence or otherwise draw a similar equivalent circuit for a transient turn off situation. Clearly label the conducting MOS channel. [30%]

Briefly discuss the advantages and disadvantages of this structure when compared to the IGBT and GTO. [20%]

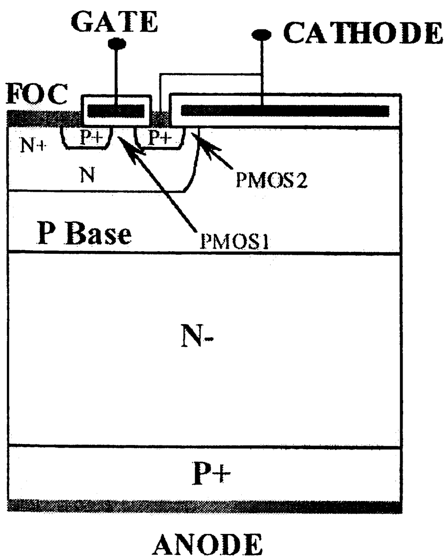

Fig. 5

5 Contrast and compare the possible use of MOSFETs, Gate Turn Off thyristors and IGBTs in the principal power circuits for the following applications:

(a) A 100 kHz resonant inverter for supplying the primary of the 40 kVA output transformer in an Xray generator; [25%]

(b) Suburban railway traction drive operating from 1400 V dc ; [25%]

(c) Lateral device structures for a power IC intended to drive a laser printer motor; [25%]

(d) An uninterruptable power supply system (UPS) for a 100 storey office building. [25%]

Make brief reference to the power losses associated with each device and the likely complexity of the gate drive circuits associated with each device.

END OF PAPER

ANSWERS

2. 2800 W 57.6 μF