Version FU/3

EGT3
ENGINEERING TRIPOS PART IIB

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Friday 2 May 2014 9.30 to 11

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**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

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

1. (a) Explain the *second breakdown* in the Bipolar Junction Transistor (BJT). Sketch the primary and second breakdown on the reverse characteristics of the BJT. [20%]

(b) Fig. 1 shows the waveforms of a Silicon Carbide BJT switch in a simplified resistive switching circuit. The switch operates at a switching frequency $f$ = 100 kHz with a duty cycle $D$ = 50%. The other parameters are: line voltage $V_{dc}$ = 50 V, off-state leakage current $I_{OFF}$ = 1 mA, on-state collector current $I_C$ = 100 A, on-state base current $I_B$ = 2 A, collector-emitter on-state voltage drop $V_{CE}$ = 2 V, base-emitter on-state voltage drop $V_{BE}$ = 2.5 V, turn-on delay time $t_d$ = 0.5 μs, turn-on current rise time $t_r$ = 0.1 μs, turn-off delay time $t_s$ = 0.5 μs, turn-off current fall time $t_f$ = 0.3 μs.

(i) Estimate the static, switching and total power losses in the switch. [40%]

(ii) Calculate the power loss due to the base current. [10%]

(iii) Draw schematically the structure of the BJT transistor and explain its operation in the on-state. [20%]

(iv) Calculate the on-state current gain of the transistor and comment on this value compared to that of an equivalent silicon based BJT. [10%]



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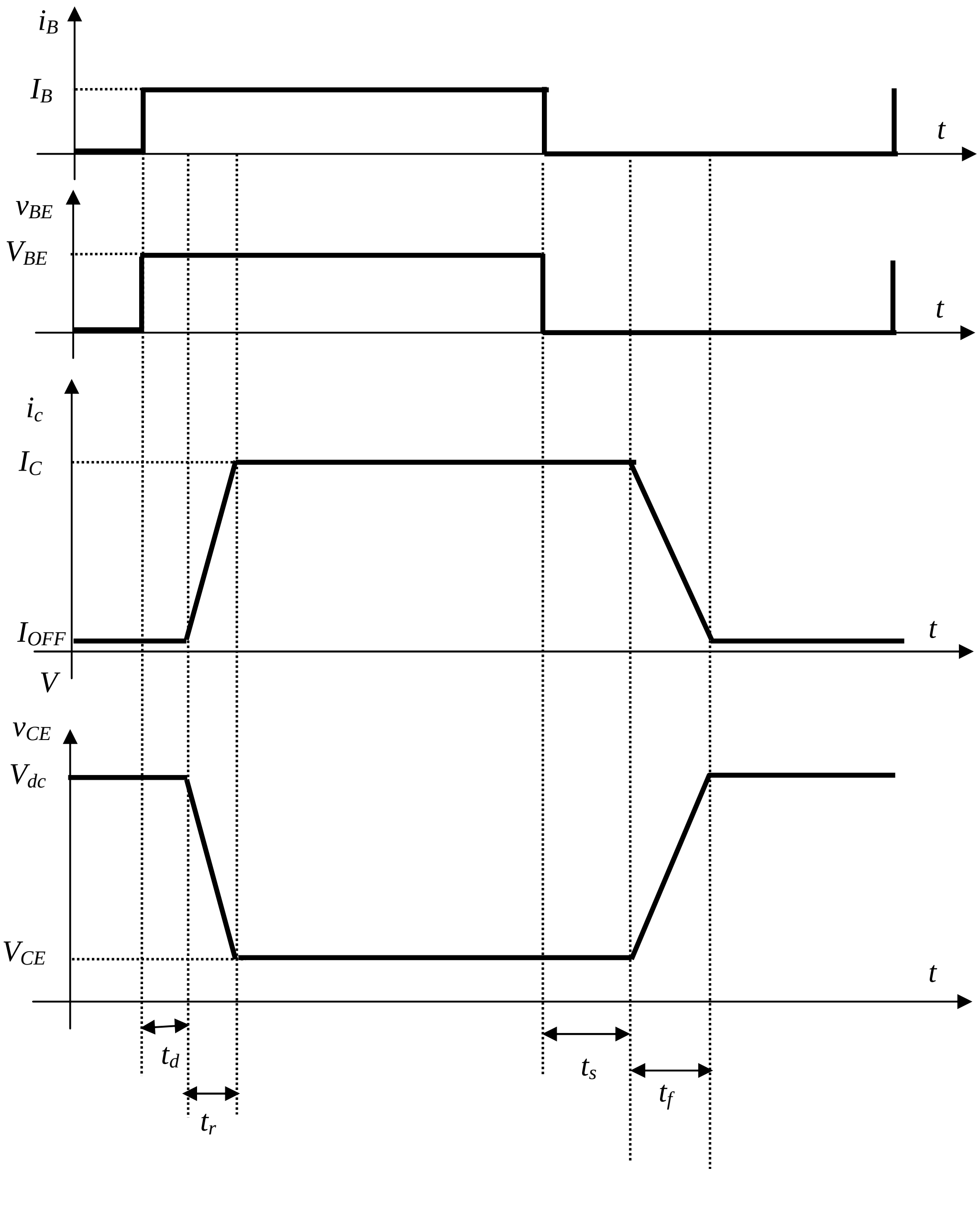


Fig.1



(TURN OVER

2 (a) Explain the latch-up effect in Insulated Gate Bipolar Transistors (IGBTs). Draw an IGBT equivalent circuit that includes the parasitic latch-up elements. Give two solutions to improve the latch-up immunity in IGBTs. [30%]

(b) Two high voltage silicon BJTs $T_1$ and $T_2$ shown in Fig. 2 are operated in parallel. Two resistors $R_1$ and $R_2$ are placed in series with the emitters of the two BJTs, $T_1$ and $T_2$, respectively.

(i) If the series resistances of $R_1$ and $R_2$ are equal, explain the mechanism through which the two series resistors help equal current sharing between the two BJTs in steady state conditions. [20%]

(ii) Propose modifications to the circuit in Fig. 2 to improve the current sharing in dynamic conditions. [20%]

(iii) In Fig. 2, $R_A$ = 63 Ω, $R_1$ = 0.5 Ω, $R_2$ = 1 Ω, the base potential of $T_1$, $V_{B1}$ = 2 V, the base voltage of $T_2$, $V_{B2}$ = 2 V and the line voltage $V_{CC}$ = 250 V. Determine the collector-emitter voltage drop for each transistor, the current flowing through each transistor and the percentage difference in current sharing. [30%]

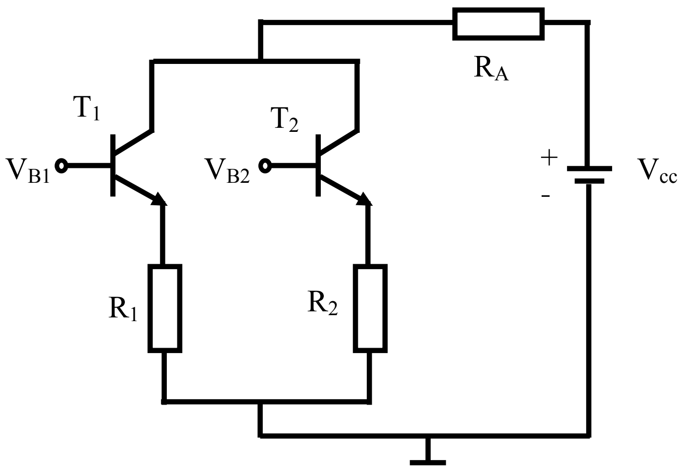


Fig.2

3. The cell structure in Fig. 3 is part of a vertical power device.

(a) Explain its operation during on-state, off-state, turn-on and turn-off. [40%]

(b) Draw an equivalent circuit for the device and briefly describe the main bipolar components. [30%]

(c) Give one advantage and two disadvantages of this device compared to a conventional Insulated Gate Bipolar Transistor (IGBT). [15%]

(d) Describe the operational consequences if the p+ doped layer under Terminal 2 would be changed to an n+ doped layer. [15%]

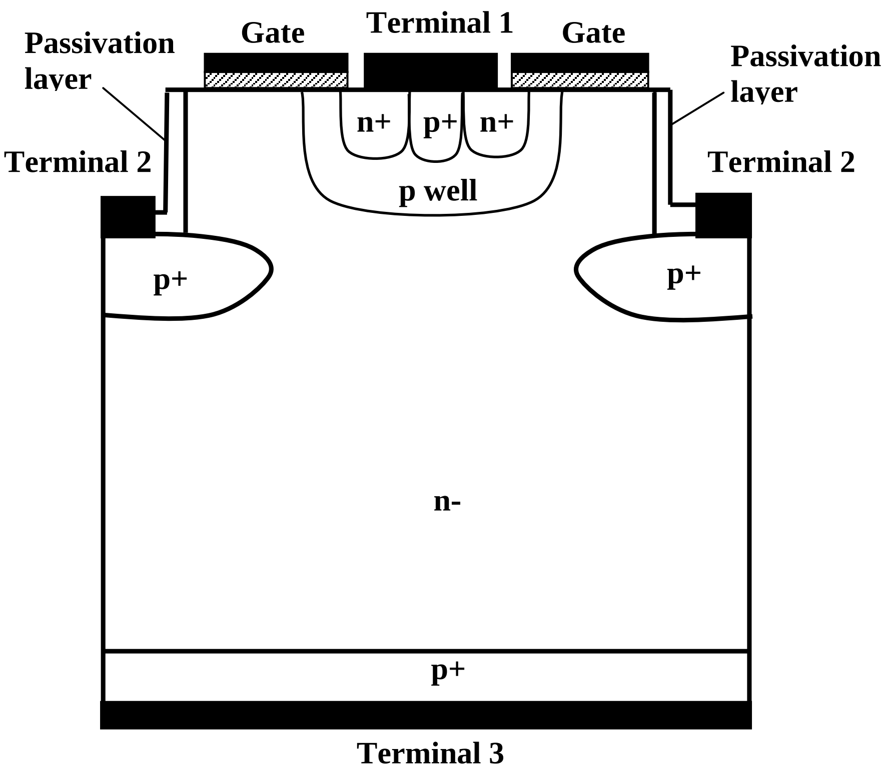


Fig. 3

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

(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) Explain all the operational consequences (and the associated trade-offs) of increasing or reducing the p-well doping in a vertical Insulated Gate Bipolar Transistor (IGBT). [25%]

(d) Explain all the operational consequences (and the associated trade-offs) of increasing or reducing the p-anode doping in a vertical IGBT. [25%]

**END OF PAPER**

Answers 4B2 – 2014

Q1. Ptotal = 134 W   P base = 2,5 W

Q2 $I_1$=2.6 A $I_2$=1.3 A, *Sharing 66.67% vs 33.33%,*
$V_{CE1}$= 3 V   *and* $V_{CE2}$= =3V