ENGINEERING TRIPOS PART IIB

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Monday 19 April 2010 9 to 10.30

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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.*

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

(a) Assuming that the switch is ideal, draw the current and voltage waveforms of the PIN diode, $D_f$, during reverse recovery operation. [30%]

(b) Assume now that the switch is a Power MOSFET and its waveforms are as shown in Fig. 2. The switch operates at a switching frequency of 10 kHz with a duty cycle $D$ = 50%. The other parameters are: $V_{dc}$ = 300 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 $V_{ON}$ = 5 V, the turn-on current rise time $t_r$ = 0.1 μs, the turn-on voltage fall time $t_d$ = 0.1 μs, the turn-off delay time $t_s$ = 0.1 μs, the turn-off voltage growth time $t_g$ = 0.2 μs, the turn-off current fall time $t_f$ = 0.1 μs.

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

(ii) Comment on the switching versus on-state losses. What would be the effect of increasing the switching frequency on the overall losses? [10%]

(iii) Give one system advantage and three disadvantages of increasing the switching frequency in the SMPS. [20%]

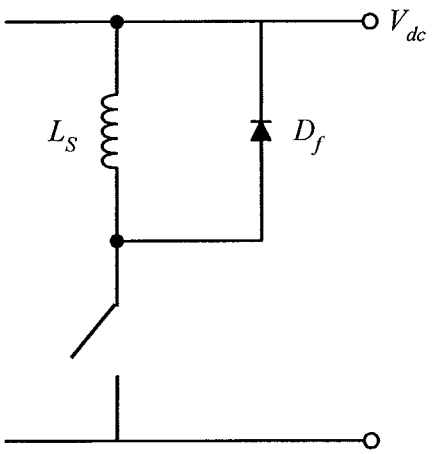


Fig. 1



(cont.

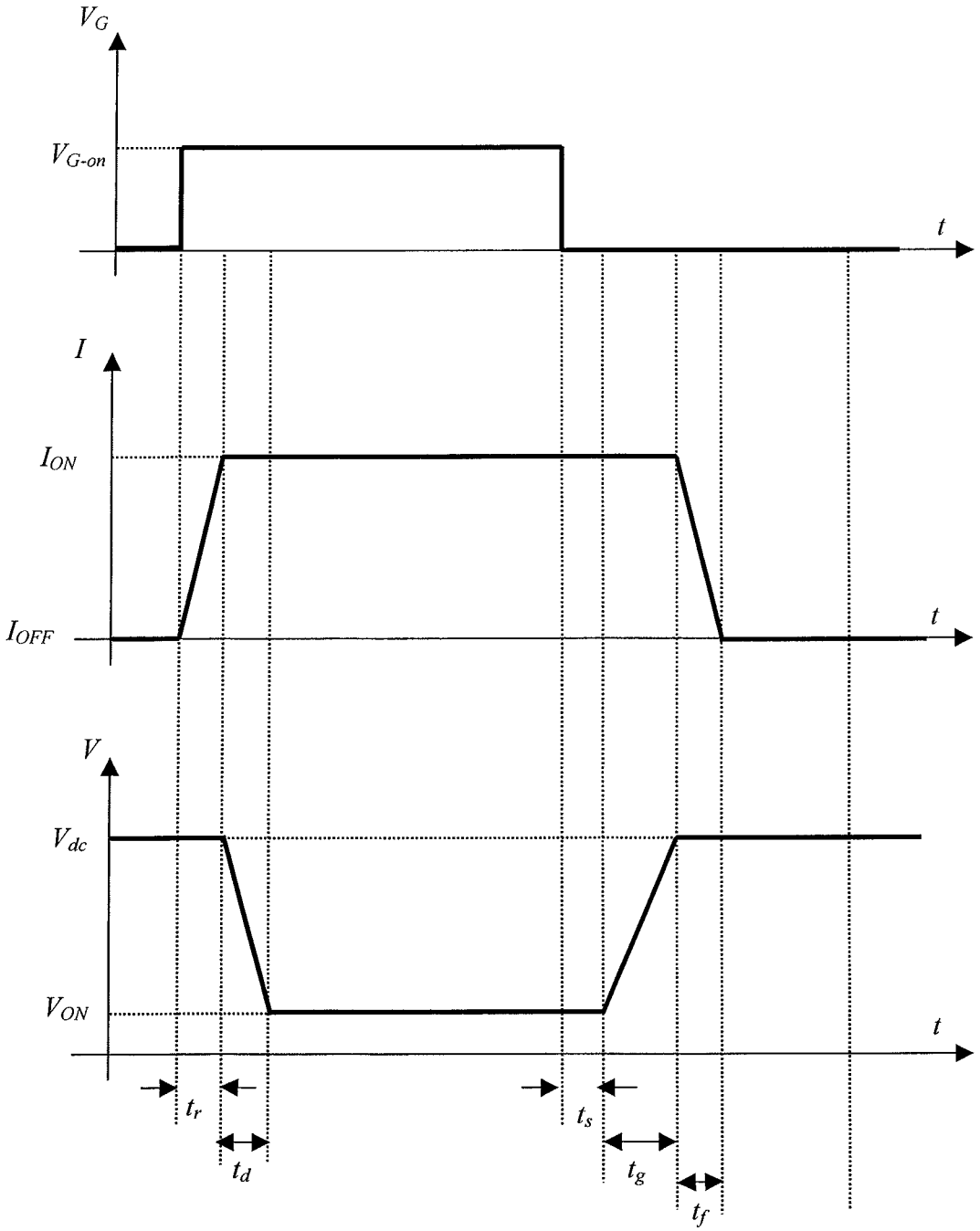


Fig. 2

2 (a) Explain the dV/dt effect in thyristors. Give two solutions to improve the *dV/dt* ratings and discuss their advantages and disadvantages. [40%]

(b) Table 1 shows some material parameters for a Silicon Power MOSFET and a Diamond Power MOSFET. Both designs are optimised to have a specific drift on-state resistance of 10 $m\Omega cm^2$.

Calculate the relative increase in the breakdown voltage of the Diamond MOSFET with respect to that of the Silicon MOSFET. State any assumptions made. [40%]

Given the result obtained, give four reasons why diamond MOSFETs are not commercially available. [20%]

| | **Silicon** | **Diamond** |
|---|---|---|
| Critical Electric field, $E_{cr}$ [V/cm] | $3 \cdot 10^5$ | $2 \cdot 10^6$ |
| Relative permittivity, $\varepsilon_r$ | 12 | 9 |
| Electron mobility, $\mu_n$ [$cm^2$/(Vs)] | 1200 | 800 |

Table 1

You may assume the following equations in the calculations of breakdown and specific on-state resistance:

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

$$R_{specific-drift} = \frac{w_{drift}}{q\mu_n N_D}$$

where $w$ is the depletion region width, $N_D$ is the doping concentration of the drift region, $w_{drift}$ is the width of the drift region, $\mu_n$ is the electron mobility in the drift region, $V$ is the reverse voltage and the other symbols have their usual meaning.

3 The structure in Fig. 3 is a vertical MOS controllable power device with a trench gate.

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

(b) Draw an equivalent circuit for the device. [25%]

(c) Give one advantage and one disadvantage of this device compared to a conventional Trench Insulated Gate Bipolar Transistor (IGBT). [10%]

(d) The device in Fig. 3 is based on vertical trench gate technology. Draw an equivalent device using a lateral technology with a planar gate. Give two advantages and two disadvantages of the vertical structure compared to the lateral structure. [25%]

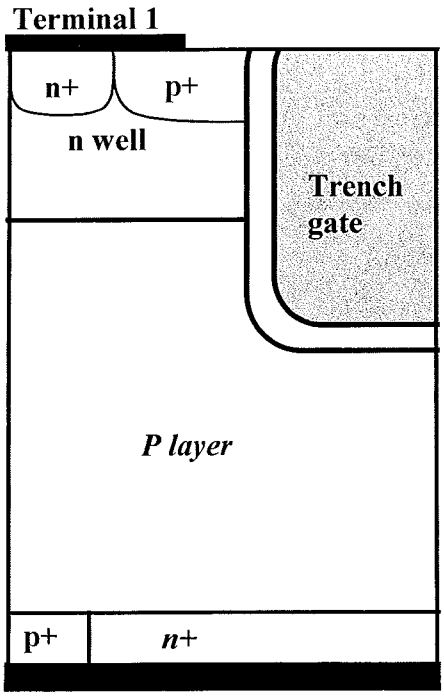


Fig. 3

4. (a) Draw schematically two AC to DC converters, first using linear electronics (LE) and second using switch mode power electronics (SMPS). Describe their operation and discuss their relative advantages and disadvantages. [40%]

(b) Using a simplified equivalent circuit find the output voltage as a function of the rectified input voltage, the duty cycle and the turn ratio of the transformer for the AC to DC SMPS converter. State any assumptions made. [30%]

(c) Explain the role of the feedback circuit in a flyback AC to DC SMPS controller. [10%]

(d) Explain briefly the performance of an IGBT compared to that of a Power MOSFET in an AC to DC power supply as a function of frequency, temperature, and power. [20%]

**END OF PAPER**

## List of Numerical answers

### Question 1

b)
$P_{on}$=2.49W
$P_{turn\text{-}on}$=0.30W
$P_{turn\text{-}off}$=0.46W
$P_{total}$ = 3.25 W

### Question 2

b) $V_{BRdiamond}/V_{BRsilicon}$=12.17