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ANSWER BOOK

Discrete semiconductor devices

Electronics · Year 13

AQA 3.13.1.1, 3.13.1.2, 3.13.1.3, 3.13.1.4 · CIE 20.3.4

17 questions · 51 marks

NAVY EDITION

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SECTION A · Warm-up

A1 The gate sits on a thin insulating oxide layer, out of contact with the silicon beneath, so it behaves as a small capacitor rather than as a conducting terminal and no steady current can enter it (1). The driver supplies only the brief charging current of that gate capacitance when the state changes (1). The common error is to treat the gate like a bipolar transistor's base and quote a steady input current. [2]

A2 Below the threshold no proper channel forms, so the drain current is negligible at any drain voltage within the device's rating (1). Above it the channel opens and widens, and provided the drain voltage is large enough to keep the channel saturated, the current climbs approximately with the square of the excess gate voltage above the threshold (1). Saying the current 'rises steadily' misses both points: a complete answer names the channel, and the shape is a square law, not a straight line. Both halves are the idealised model: below threshold a small leakage still flows, and the square law is the saturated behaviour, not the behaviour at every drain voltage. [2]

A3 The zener goes across the load, **reverse** biased, so that it sits in breakdown at its rated voltage (1). The series resistor sits between the raw supply and the diode and drops whatever the supply has left over, which is what sets the current and lets the output stay put when the supply wanders (1). Drawing the zener forward biased, or leaving the series resistor out and shorting the supply through the diode, are the two common errors. [2]

A4 It is used **reverse** biased, so that almost nothing flows in the dark and every absorbed photon adds to the reverse current (1). The photocurrent is **proportional** to the illumination, so the response is linear and one constant converts current to illumination across the range, where a curve would be needed for a device that is not (1). That constant still comes from a calibration against a known source: linearity saves the shape of the graph, not the fixing of its scale. Writing 'forward biased', or claiming the current depends on the applied pd, are the marks most often thrown away here: the characteristics are flat, so the light sets the current. [2]

A5 It measures magnetic **flux** density, the Hall voltage across the slab being proportional to B when the current through the slab is held constant (1). The Hall voltage is largest when the field is perpendicular to the face of the slab, so the probe is turned until the reading is a maximum and that value is taken (1). Reading the probe at any old angle, and quoting the number as though it were B, is the common error. [2]

A6 It responds in nanoseconds, while carriers in an LDR take milliseconds to build up and longer to disperse, so an LDR cannot follow anything flickering faster than a few hundred hertz (1). Its photocurrent is proportional to the illumination, whereas an LDR's resistance is not, so the photodiode reproduces the pulse shape faithfully (1). Answering on cost alone earns nothing: the comparison is won on response time and linearity. [2]

SECTION B · Standard

B1 The excess above threshold is 3.0 - 2.0 = 1.0 V, so $k = 0.10/1.0^2 = 0.10\ \text{A V}^{-2}$ (1). At 4.5 V the excess is 4.5 - 2.0 = 2.5 V (1), so $I_D = 0.10 \times 2.5^2 = 0.625$ A (1). Squaring the gate voltage itself instead of the excess above the threshold is the common error, and it gives 2.02 A, three times too big. [3]

B2 Channel and heater are in series, so R = 6.0 + 0.12 = 6.12 Ω and I = 9.0/6.12 = 1.47 A (1). Heater pd = 1.47 × 6.0 = 8.82 V (1). MOSFET power = $I^2R = 1.47^2 \times 0.12 = 0.26$ W, against 13.0 W in the heater (1). Using the full 9.0 V across the channel instead of I^2R is the common error; the channel only ever has 0.18 V across it. [3]

B3 The resistor drops 15 - 5.1 = 9.9 V, so I = 9.9/390 = 25.4 mA (1). The load takes 12 mA of that, leaving 25.4 - 12 = 13.4 mA in the zener (1). $P = V_ZI = 5.1 \times 13.4 \times 10^{-3} = 68$ mW (1). Dividing the whole 15 V by 390 Ω is the common error: only the leftover 9.9 V appears across the resistor. [3]

B4 $V = IR = 24 \times 10^{-6} \times 75 \times 10^3 = 1.8$ V (1). Photocurrent is proportional to illumination, so three times the light gives 3 × 24 = 72 μA (1) and V = 5.4 V (2 s.f.) (1). Treating the diode like a resistor, so that trebling the light somehow changes its resistance instead of its current, is the common error: the flat characteristics mean it behaves as a current source and the light alone sets the current. [3]

B5 Sensitivity = 2.4/0.20 = 12 mV T^{-1} (1), the Hall voltage being proportional to B at constant current (1). Output = 12 × 0.55 = 6.6 mV (1). Forgetting that the sensor current must be held constant, and so treating the sensitivity as fixed when it is not, is the common error; so is dividing the wrong way round and quoting 0.083 T mV^{-1}. [3]

B6 The resistor drops 9.0 - 5.1 = 3.9 V, so I = 3.9/390 = 10.0 mA (1). Every milliamp the load takes comes out of that current, so the largest load current is 10.0 mA (1), and at that point the zener current has fallen to zero (1). Ask for more and the zener current would have to run backwards, which it cannot: the output sags below 5.1 V and regulation is lost. Quoting the load current at the **highest** supply voltage is the common error, because the worst case is always the lowest supply. [3]

B7 The excess above threshold goes from 1.0 V to 4.0 V, a factor of 4, and the current follows its square, a factor of 16 (1). I_D = 16 × 0.10 = 1.6 A (1). Doubling the gate voltage and expecting four times the current is the common error: the square law acts on the excess above the threshold, not on V_{GS} itself. [2]

SECTION C · Stretch

C1 Worst case for the resistance is the lowest supply, where its drop is only 9.0 - 5.1 = 3.9 V (1). It must still carry the load's 15 mA plus the zener's 5.0 mA, that is 20 mA, so R ≤ $3.9/(20 \times 10^{-3})$ = 195 Ω (1). With R = 180 Ω the resistor carries 21.7 mA at 9.0 V in, comfortably above the 20 mA needed (1). At 15.0 V in the resistor carries 9.9/180 = 55 mA (1), and with the load disconnected all of it goes through the zener, giving P = 5.1 × 55 × 10^{-3} = 280 mW (1), inside the 400 mW rating (1). The resistor itself dissipates 9.9 × 55 × 10^{-3} = 0.54 W, so a 1 W resistor is needed (1). Two common errors sink this design: testing the resistance at the highest supply instead of the lowest, and testing the zener's power with the load connected instead of disconnected. The worst case for current is minimum supply; the worst case for zener power is maximum supply with no load. [7]

C2 Charge needed: Q = CV = 1.5 × 10^{-9} × 5.0 = 7.5 × 10^{-9} C (1). At a steady 4.0 mA, t = Q/I = 7.5 × 10^{-9}/(4.0 × 10^{-3}) (1) = 1.87 × 10^{-6} s, about 1.9 µs (1). Once the gate is charged the current falls to **zero**, because the oxide insulates the gate from the channel (1). Quoting a steady gate current of 4.0 mA is the common error; the 4.0 mA flows only while the gate capacitance is charging. [4]

C3 Sensitivity = 2.4/0.20 = 12 mV T^{-1}, so the peak output is 12 × 0.45 = 5.4 mV (1). Pulse rate = 120/2.0 = 60 pulses per second (1). Four magnets give four pulses per revolution, so the shaft turns 60/4 = 15 times a second (1), that is 15 × 60 = 900 revolutions per minute (1). Reporting 60 rev s^{-1}, one pulse per revolution, is the common error: count the magnets before dividing. [4]

C4 At 3 units the photocurrent is 3 × 20 = 60 µA (1). R = V/I = 2.5/(6.0 × 10^{-5}) = 41.7 kΩ (1). With 43 kΩ the pd is 6.0 × 10^{-5} × 43 × 10^{3} = 2.58 V (1). An LDR takes milliseconds for its carriers to build up and disperse, so at 1 MHz, a microsecond per bit, it could not follow the light at all, while a photodiode responds in nanoseconds (1). Two common errors here: dividing current by voltage and quoting 24 µA V^{-1} as a resistance, and arguing the comparison on cost rather than on response time and linearity. [4]