UNIVERSITY OF ESWATINI

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MAIN EXAMINATION 2019/2020

TITLE OF PAPER	:	SOLID STATE ELECTRONICS
COURSE CODE	:	EEE521
TIME ALLOWED	:	THREE HOURS

USEFUL INTSRUCTIONS:

1. There are five questions in this paper, and each question is worth 25 marks. Answer any four questions in your preferred order.
2. Additional materials included in this paper are a list of useful constants, special integrals, and the periodic table.

THIS PAPER SHOULD NOT BE OPENED UNLESS OTHERWISE ADVISED TO DO SO BY THE INVIGILATOR

THIS PAPER CONSISTS OF 10 PAGES WITH COVER PAGE AND ADDITIONAL BACK PAGE INCLUDED

Question One [25 marks]

(a) Name six categories of semiconductors. (6)

(b) With the aid of appropriate chemical formulas, discuss the extraction of silicon (Si) from silicon dioxide (SiO_2). (4)

(c) Determine the fraction of an *fcc* unit cell volume filled with hard spheres. (4)

(d) Sketch a cubic lattice and show four {111} planes with different orientations. Repeat this for {110} planes. (4)

(e) Differentiate between a primitive cell and a unit cell, and further state the utility of both concepts. (2)

(f) Fig. 1.1 is a schematic description of the Czochralski technique of semiconductor crystal growth. Describe semiconductor crystal growth by this technique. (5)

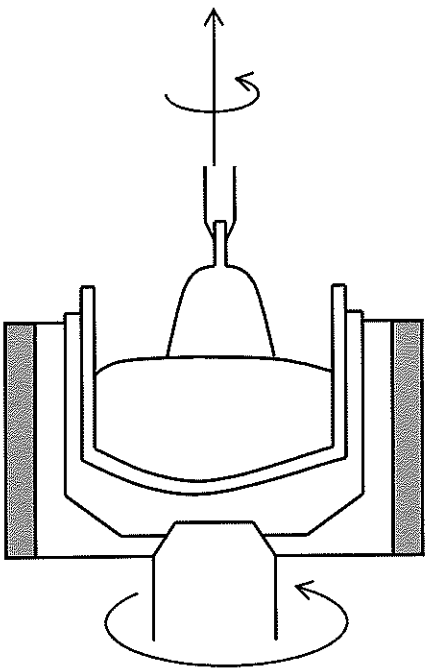

Fig. 1.1

Question Two [25 marks]

(a) State two means by which the electrical conductivity of a semiconductor can be varied. (2)

(b) Fig. 2.1 shows the experimental setup for the determination of maximum kinetic energies of ejected electrons during the photoelectric effect.

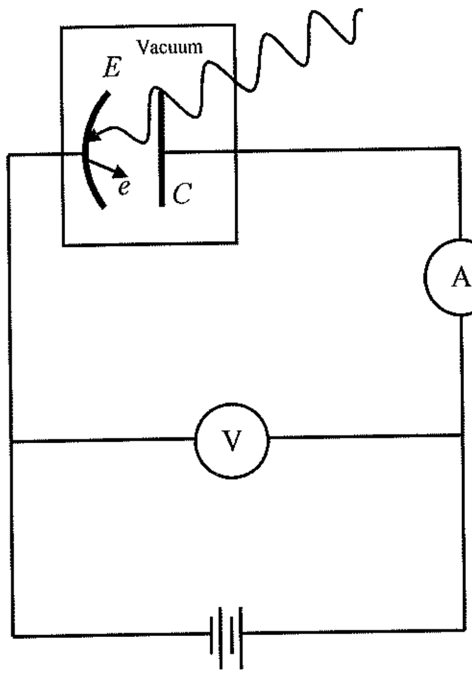

Fig. 2.1

(i) Describe this experiment. (4)

(ii) Classical physics predicted that the number of photoelectrons ejected from the surface of a metal is unaffected by the intensity of incident light. Experiment showed that an increased number of electrons are ejected as the intensity of light increases. Explain this experimental observation. (3)

(c) Fig. 2.2 shows electronic transitions between atomic orbits according to the Bohr model for the hydrogen atom.

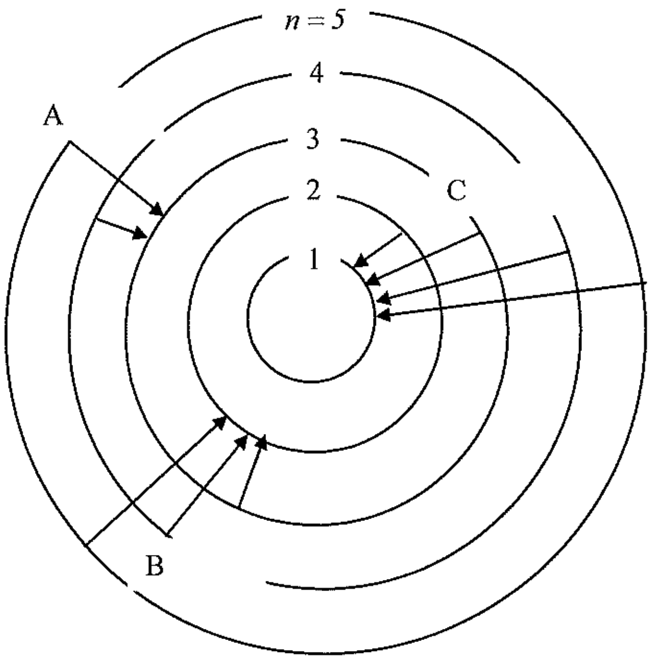

Fig. 2.2

(i) Name the emission spectral groups labeled A – C. (3)

(ii) Show that the frequency of a light photon emitted during the transition of an electron from orbit n_2 to orbit n_1 is given by $\nu_{21} = \left[\frac{mq^4}{32\pi^2\varepsilon_0^2\hbar^2 h}\right]\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$, where symbols have their usual meanings. (10)

(iii) Using this diagram, or otherwise, explain the Ritz combination principle. (3)

Question Three [25 marks]

(a) Given that a plane wave has the wave function $\psi(x) = Ae^{jk_x x}$, deduce an expression for the expectation value of p_x the x-component of its momentum. (5)

(b) A particle in an infinite potential well from $x = 0$ to $x = L$ in the $n = 1$ state has the wave function $\psi(x) = \sqrt{\frac{2}{L}} sin\left(\frac{\pi x}{L}\right)$. Deduce an expression for the probability of finding a particle that lies anywhere from $x = 0$ to $x = l$ such that $0 \le l \le L$. (5)

(c) The time-dependent wave function for an electron of mass m is $\psi(x, t) = Ae^{-a[(mx^2/h)+jt]}$, where $j = \sqrt{-1}$ and real $A \neq a > 0$.

(i) Find A. (3)

(ii) Find the expectation value $\langle x^2 \rangle$ for the electron's position. (2)

(d) Schematically show the number of electrons in the various subshells of an atom that has the electronic shell structure $1s^2 2s^2 2p^4$ and an atomic weight of 21. Indicate the number of electrons and protons that exist in the nucleus, and determine by stating the reason whether this atom is chemically reactive or not. (5)

(e) Derive an expression for the effective mass of an electron in a band, and further show that it is determined by the band curvature. (5)

Question Four [25 marks]

(a) (i) State two basic circuit functions performed by transistors. (2)

(ii) Fig. 4.1 is a circuit diagram that represents the principle of operation of a FET.

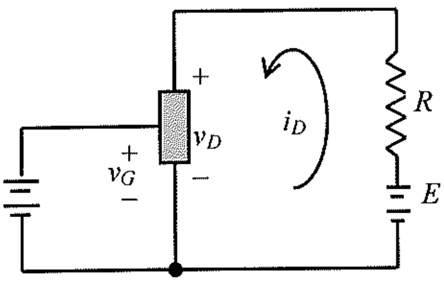

Fig. 4.1

1. State the function of each of the two circuit loops shown. (2)
2. Describe the principle of operation of the device. (2)
3. Briefly outline how the steady state values of i_D and v_D can be found. (3)

(b) Fig. 4.2 is a schematic of the geometry of an *n*-channel JFET.

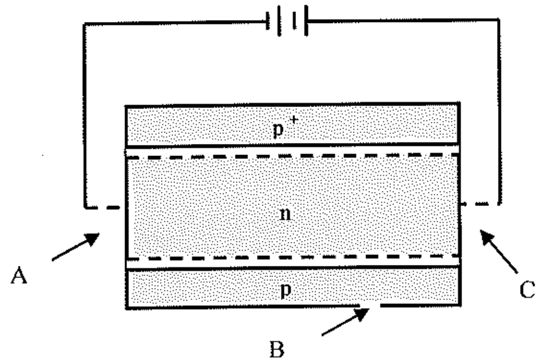

Fig. 4.2

(i) Name the components labeled A – C. (3)

(ii) Describe the characteristic features and operation of the device. (4)

(iii) What would be the implication of making the channel *p*-type and the other regions *n*-type? (1)

(iv) Draw a diagram of the n-channel JFET to illustrate its geometry of the when the gate is short-circuited to the source and the drain current is increased. Explain your geometry. (5)

(v) Explain what happen to the above geometry as the drain voltage and current are further increased. (3)

Question Five [25 marks]

(a) The conducting channel of a certain semiconductor device is depleted by using a reverse-biased Schottky barrier instead of a $p-n$ junction.

(i) Name the device that operates by this mechanism. (1)

(ii) Draw such a device with a channel of n-GaAs. Explain why it has no body contact. (3)

(iii) State one use of such a device. (1)

(iv) Why is GaAs preferred over Si for the channel of this device? (2)

(v) Why is the substrate normally doped with chromium (Cr)? (2)

(vi) What is the implication of applying a reverse bias to the Schottky gate? (2)

(b) Fig. 5.1 shows a cross-sectional view of an n-channel MOSFET.

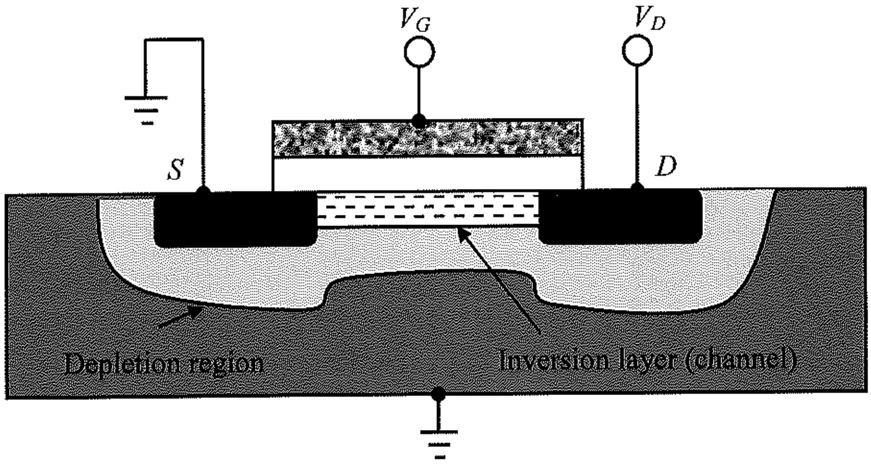

Fig. 5.1

(i) Outline the impact of applying a positive voltage to the gate relative to the substrate. (3)

(ii) State the cause and implication of the conducting channel becoming less p-type. (3)

(iii) Briefly describe the design and operation of the p-type version of the device. (5)

(c) Why are GaAs solar cells more efficient than Si solar cells? (3)

Useful Constants and Conversion Factors, and the Periodic Table of Elements

Conversion factors	Physical constants	
$1\,\text{eV} = 1.60218 \times 10^{-19}$ J	Speed of light	$c = 3.00 \times 10^{8}$ m/s
	Planck's constant	$h = 6.63 \times 10^{-34}$ J.s
	Boltzmann constant	$k = 1.38 \times 10^{-23}$ J/K
	Electronic charge	$e = 1.602 \times 10^{-19}$ C
	Electron mass	$m_e = 9.11 \times 10^{-31}$ kg
	Proton mass	$m_p = 1.67 \times 10^{-27}$ kg
	Permittivity of free space	$\varepsilon_o = 8.8542 \times 10^{-12}\ C^2N^{-1}m^{-2}$

The periodic table of elements

I	II											III	IV	V	VI	VII	VIII
^{1}H 1.00																	^{2}He 4.00
^{3}Li 6.94	^{4}Be 9.01											^{5}B 10.8	^{6}C 12.0	^{7}N 14.0	^{8}O 16.0	^{9}F 19.0	^{10}Ne 20.2
^{11}Na 23.0	^{12}Mg 24.3											^{13}Al 27.0	^{14}Si 28.1	^{15}P 31.0	^{16}S 32.1	^{17}Cl 35.5	^{18}Ar 40.0
^{19}K 39.1	^{20}Ca 40.1	^{21}Sc 45.0	^{22}Ti 47.9	^{23}V 50.9	^{24}Cr 52.0	^{25}Mn 54.9	^{26}Fe 55.9	^{27}Co 58.9	^{28}Ni 58.7	^{29}Cu 63.5	^{30}Zn 65.4	^{31}Ga 69.7	^{32}Ge 72.6	^{33}As 74.9	^{34}Se 79.0	^{35}Br 79.9	^{36}Kr 83.8
^{37}Rb 85.5	^{38}Sr 87.6	^{39}Y 88.9	^{40}Zr 91.2	^{41}Nb 92.9	^{42}Mo 95.9	^{43}Tc 98.9	^{44}Ru 101	^{45}Rh 103	^{46}Pb 106	^{47}Ag 109	^{48}Cd 112	^{49}In 115	^{50}Sn 119	^{51}Sb 122	^{52}Te 128	^{53}I 127	^{54}Xe 131
^{55}Cs 133	^{56}Ba 137		^{72}Hf 178	^{73}Ta 181	^{74}W 184	^{75}Re 186	^{76}Os 190	^{77}Ir 192	^{78}Pt 195	^{79}Au 197	^{80}Hg 201	^{81}Tl 205	^{82}Pb 207	^{83}Bi 209	^{84}Po 210	^{85}At 210	^{86}Rn 222
^{87}Fr 223	^{88}Ra 226		^{104}Rf	^{105}Db	^{106}Sg	^{107}Bh	^{108}Hs	^{109}Mt	^{110}Ds	^{111}Rg	^{112}Cn	^{113}Nh	^{114}Fl	^{115}Me	^{116}Lv	^{117}Ts	^{118}Og

Special definite and indefinite integrals

$$\int_0^1 e^{x\cdot\ln a+(1-x)\cdot\ln b}\,dx = \int_0^1 \left(\frac{a}{b}\right)^x \cdot b\,dx = \int_0^1 a^x \cdot b^{1-x}\,dx = \frac{a-b}{\ln a - \ln b} \quad \text{for } a>0, b>0, a\neq b$$

$$\int_0^\infty e^{ax}\,dx = \frac{1}{a} \quad (a<0)$$

$$\int_0^\infty e^{-ax^2}\,dx = \frac{1}{2}\sqrt{\frac{\pi}{a}} \quad (a>0)$$

$$\int_{-\infty}^\infty e^{-ax^2}\,dx = \sqrt{\frac{\pi}{a}} \quad (a>0)$$

$$\int_{-\infty}^\infty e^{-ax^2+bx}\,dx = \sqrt{\frac{\pi}{a}}e^{\frac{b^2}{4a}} \quad (a>0)$$

$$\int_{-\infty}^\infty xe^{-ax^2+bx}\,dx = \frac{\sqrt{\pi}b}{2a^{3/2}}e^{\frac{b^2}{4a}} \quad (a>0)$$

$$\int_{-\infty}^\infty x^2e^{-ax^2+bx}\,dx = \frac{\sqrt{\pi}\left(2a+b^2\right)b}{8a^{7/2}}e^{\frac{b^2}{4a}} \quad (a>0)$$

$$\int_{-\infty}^\infty e^{-ax^2}e^{-2bx}\,dx = \sqrt{\frac{\pi}{a}}\,e^{\frac{b^2}{a}} \quad (a>0)$$

$$\int_{-\infty}^\infty x\,e^{-a(x-b)^2}\,dx = b\sqrt{\frac{\pi}{a}}$$

$$\int_{-\infty}^\infty x^2e^{-ax^2}\,dx = \frac{1}{2}\sqrt{\frac{\pi}{a^3}} \quad (a>0)$$

$$\int_{-\infty}^\infty e^{-\left(ax^2+bx+c\right)}\,dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}\,e^{\left(\frac{b^2-4ac}{4a}\right)}$$

$$\int \sin^2 ax\,dx = \frac{x}{2} - \frac{1}{4a}\sin 2ax + C = \frac{x}{2} - \frac{1}{2a}\sin ax\cos ax + C$$