UNIVERSITY OF ESWATINI

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MAIN EXAMINATION 2018/2019

TITLE OF PAPER:	SOLID STATE ELECTRONICS
COURSE CODE:	EE429
TIME ALLOWED:	THREE HOURS

USEFUL INTSRUCTIONS:

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

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THIS PAPER CONSISTS OF 9 PAGES WITH COVER PAGE AND ADDITIONAL BACK PAGE INCLUDED

Question One [25 marks]

(a) In tabular form, differentiate between conventional electronics and modern solid-state electronics. (4)

(b) Copy and complete the following table to give examples on the classes of semiconductors depicted per column. (10)

Elemental (group)	Binary Compounds			
	III-V	II-VI	I-VII	IV-VI

(c) With aid of appropriate chemical formulas and using the keywords listed below, describe the formation of a single-crystal of electronic-grade Si (EGS). **Keywords**: *raw material*, *extraction process*, *reaction by-products*, and *impurities*. (6)

(d) For a *bcc* lattice that consists of identical atoms and with a lattice constant $a = 5\ \mathring{A}$, calculate the maximum packing fraction and the radii of the atoms that are treated as hard spheres with their nearest neighbors touching. (5)

Question Two [25 marks]

(a) Name the plane shown in fig. 2.1. (3)

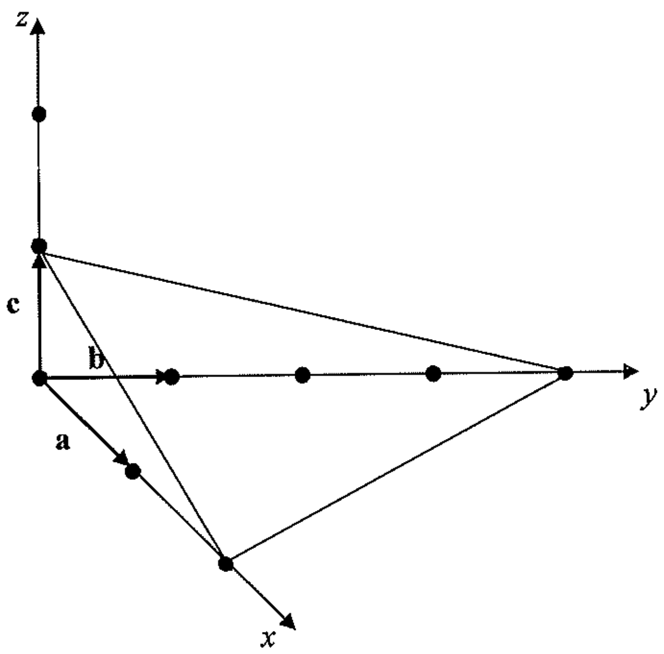

Fig. 2.1

(b) A Si crystal is to be grown using the Czochralski technique such that the resultant ingot must contain 10^6 phosphorus atoms per cubic centimeter.

(i) Given that the distribution coefficient $k_d = 0.35$ for phosphorus in Si, determine the concentration of phosphorus atoms in the melt that yield the above impurity concentration in the crystal ingot. (2)

(ii) Given that the initial load of Si in the crucible is 5 kg and the atomic weight of phosphorus is 31 g/mole, determine the grams of phosphorus that should be added. (5)

{Hint: $m_P = \dfrac{N_P \times \text{Atomic Weight}}{\text{Avogadro's Number}}$}

(c) Various techniques are used for semiconductor crystal growth. Amongst those techniques:

(i) Distinguish between the Czochralski and Bridgman techniques of semiconductor crystal growth. (4)

(ii) With the aid of well written chemical formulas, describe the formation of Si and GaAs thin films by metal-oxide chemical vapour deposition (MOCVD). (6)

(iii) Describe semiconductor crystal growth by molecular beam epitaxy (MBE). (5)

Question Three [25 marks]

(a) Copy and complete the following table to distinguish amongst the various types of materials depicted in the columns. (6)

Conductor	Insulator	Semiconductor

(b) An experiment by Einstein involved the absorption of optical energy by electrons in a metal, and this was later referred to as the *photoelectric effect*.

(i) Classical physics predicted that the number of photoelectrons ejected from the surface of a metal is unaffected by the intensity of incident light. Experiments, however, showed that an increased number of electrons are ejected as the intensity increases. Account for the results of experiments. (2)

(ii) Classical physics predicted that the kinetic energy of photoelectrons increases as the intensity of incident light increases. However, experiments showed that the kinetic energy does not change with intensity. Justify the results of experiments. (2)

(c) The Bohr model was initially constructed for the hydrogen atom, and it assumes that an electron orbits about the nucleus at a radius r as shown in fig. 3.1.

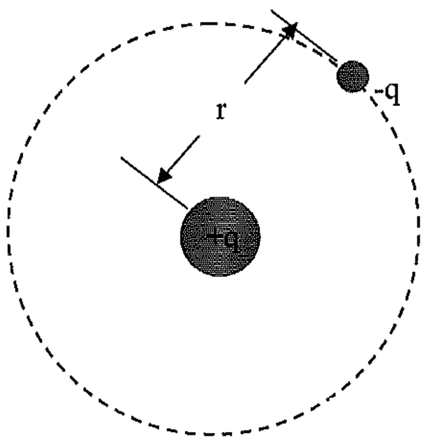

Fig. 3.1

(i) By first deriving an expression for the energy of the n^{th} electron orbit, show that the energy difference between orbits n_1 and n_2 is $E_{n_2} - E_{n_1} = \frac{mq^4}{2\hbar^2 K^2}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$ (12)

(ii) Show that the frequency of a photon emitted during the transition of an electron from orbit n_2 to orbit n_1 is given by $v_{21} = \left[\frac{mq^4}{2\hbar^2 hK^2}\right]\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$ (3)

Question Four [25 marks]

(a) Apply the uncertainty principle to predict the velocity of the electron in a ^{1}H atom given that $m_e = 9.11\times10^{-31}$ kg and $\Delta x \approx 10^{-10}$ m. (3)

(b) Quantum mechanics was developed via *wave mechanics* and matrix mechanics, the results of which converged to the same solution.

(i) State *three* postulates of quantum mechanics. (3)

(ii) The classical expression for the total energy of a particle is $E = \frac{p^2}{2m} + U$, where *p* is the momentum, *m* is the mass, and *U* is the potential energy. Using you knowledge of quantum mechanical operators, or otherwise, derive the Schrödinger wave equation. (5)

(iii) 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)

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

(iv) With the aid of a clearly labeled diagram, describe *quantum mechanical tunneling* and the role it plays in solid state devices. (5)

(c) With the aid of an (*E*, **k**) band diagram, describe the classification of semiconductors into *direct* and *indirect*. (4)

Question Five [25 marks]

(a) Given that argon (Ar) has an atomic number $Z = 18$, write down its electronic configuration using your knowledge of the quantum numbers denoted by n, l, m, and s. (6)

(b) Differentiate between an electron in a solid and an electron in isolated atom. (4)

(c) Classify semiconductors into *extrinsic* and *intrinsic*, and hence show understanding of the phrases p-type and n-type semiconductors. (5)

(d) With the aid of well explained equations, show that the current contribution by a hole in the valence band is equivalent to that of a positively charged particle with velocity v_j, where v_j is the velocity of the j^{th} electron removed during the creation of that hole. (5)

(e) Show that the effective mass of an electron in a band is determined by the curvature of the band, and state its nature near the top of the valence band. (5)

{Hint: The momentum $\boldsymbol{p} = \hbar \boldsymbol{k}$ and energy $E = \frac{p^2}{2m}$}

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

Conversion factors

$1\,\text{eV} = 1.60218 \times 10^{-19}$ J

Physical constants

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																	^{2}He
^{3}Li	^{4}Be											^{5}B	^{6}C	^{7}N	^{8}O	^{9}F	^{10}Ne
^{11}Na	^{12}Mg											^{13}Al	^{14}Si	^{15}P	^{16}S	^{17}Cl	^{18}Ar
^{19}K	^{20}Ca	^{21}Sc	^{22}Ti	^{23}V	^{24}Cr	^{25}Mn	^{26}Fe	^{27}Co	^{28}Ni	^{29}Cu	^{30}Zn	^{31}Ga	^{32}Ge	^{33}As	^{34}Se	^{35}Br	^{36}Kr
^{37}Rb	^{38}Sr	^{39}Y	^{40}Zr	^{41}Nb	^{42}Mo	^{43}Tc	^{44}Ru	^{45}Rh	^{46}Pb	^{47}Ag	^{48}Cd	^{49}In	^{50}Sn	^{51}Sb	^{52}Te	^{53}I	^{54}Xe
^{55}Cs	^{56}Ba		^{72}Hf	^{73}Ta	^{74}W	^{75}Re	^{76}Os	^{77}Ir	^{78}Pt	^{79}Au	^{80}Hg	^{81}Tl	^{82}Pb	^{83}Bi	^{84}Po	^{85}At	^{86}Rn
^{87}Fr	^{88}Ra		^{104}Rf	^{105}Db	^{106}Sg	^{107}Bh	^{108}Hs	^{109}Mt	^{110}Ds	^{111}Rg	^{112}Cn	^{113}Nh	^{114}Fl	^{115}Mc	^{116}Lv	^{117}Ts	^{118}Og