UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MAIN EXAMINATION 2017/2018

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) Semiconductors exist either as single elements or compounds. Describe and account for the difference between III-V binary compounds and their group IV elemental counterparts. (4)

(b) Some II-VI binary compounds have large band gaps, yet others have small band gaps in their electronic band structures. Name one example of each case and state their uses. (4)

(c) Fig. 1.1 is a schematic illustration of the *Czochralski* crystal growth technique.

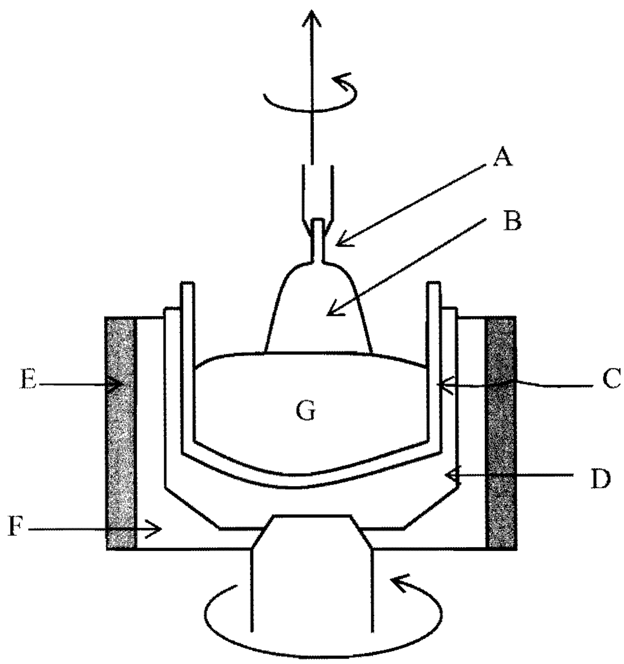

Fig. 1.1

(i) Name the components labeled A – G. (7)

(ii) Briefly describe the growth of a bulk Si crystal by this technique. (10)

Question Two [25 marks]

(a) Distinguish between *conductors*, *insulators*, and *semiconductors* in relation to their electronic band structures. (6)

(b) Consider the incidence of two different types of light on a *zinc* (Zn) metal surface. One light type is *ultraviolet* (UV) light of wavelength λ = 300 nm, and the other is *red laser* light of wavelength λ = 700 nm. Given that the work function of Zn metal is given by $q f = 6.9 \cdot 10^{-19}$ J :

(i) Calculate the energy per photon of the UV light in eV. (2)

(ii) Explain why the above energy is enough or not enough for the ejection of electrons from the surface of Zn. (1)

(iii) Calculate the total number of photons emanating from the red laser light in 60 seconds if its intensity is 1.0 mW. (4)

(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. 2.1.

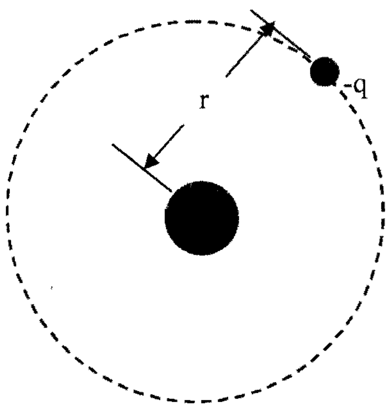

Fig. 2.1

(i) State the three postulates of this model. (3)

(ii) Defining all parameters involved, show that this model depicts that the radius of the n^{th} electron orbit is given by the expression below: (4)

$$r_n = \frac{Kn^2h^2}{mq^2}$$

(iii) With all parameters as defined above, show that the total energy of an electron in the n^{th} orbit is given by the following expression: (5)

$$E_n = -\frac{mq^4}{2n^2h^2K^2}$$

Question Three [25 marks]

(a) Distinguish between an electron in an isolated atom and an electron in a solid. (3)

(b) A solution to the Schrödinger wave equation for two electrons centered on the nuclei of two neighboring atoms shows that their resultant composite wave functions are linear combinations of the individual atomic orbitals (LCAO). With the aid of a clearly labeled diagram, explain the meaning of:

(i) Antibonding orbital (3)

(ii) Bonding orbital (3)

(c) Distinguish between an *intrinsic* semiconductor and an *extrinsic* semiconductor. (6)

(d) A single electron in a crystal is assumed to travel through a perfectly periodic lattice, and its wave function takes the form of a *plane wave* moving in one-dimension. Its wave function is thus given by:

$$y_k(x) = U(\mathbf{k}_x, x)e^{jk_x x}$$

where $U(\mathbf{k}_x, x)$ *modulates the wave function according to the periodicity of the lattice* and the propagation constant **k** called a *wave vector*. Assuming that U is constant for an essentially free electron, show that the x-component of its momentum is given by $\langle p_x \rangle = \mathbf{hk}_x$. (6)

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

Question Four [25 marks]

(a) Fig. 4.1 is a summary of the steps involved during the fabrication of a p-n junction on a Si substrate.

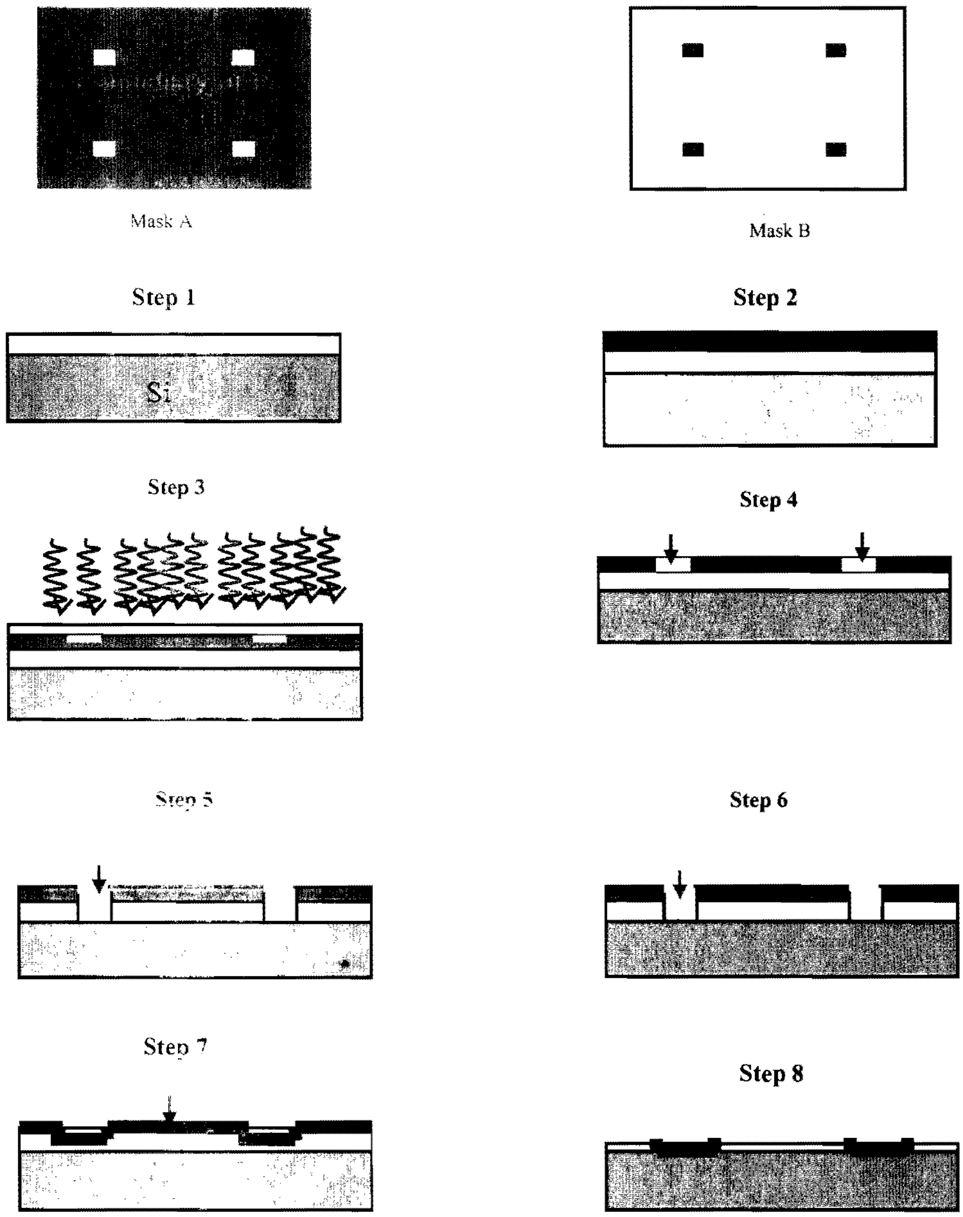

Fig. 4.1

(i) State three functions of p-n junctions. (3)

(ii) State uses of the masks A and B in fig. 4.1. (2)

(iii) Write a brief a summary on the steps 1 – 8 of p-n junction fabrication. (8)

(b) One mechanism by which dopants are introduced during p-n junction fabrication is called *ion implantation*. Fig. 4.2 is a schematic diagram of an impurity ion implantation system.

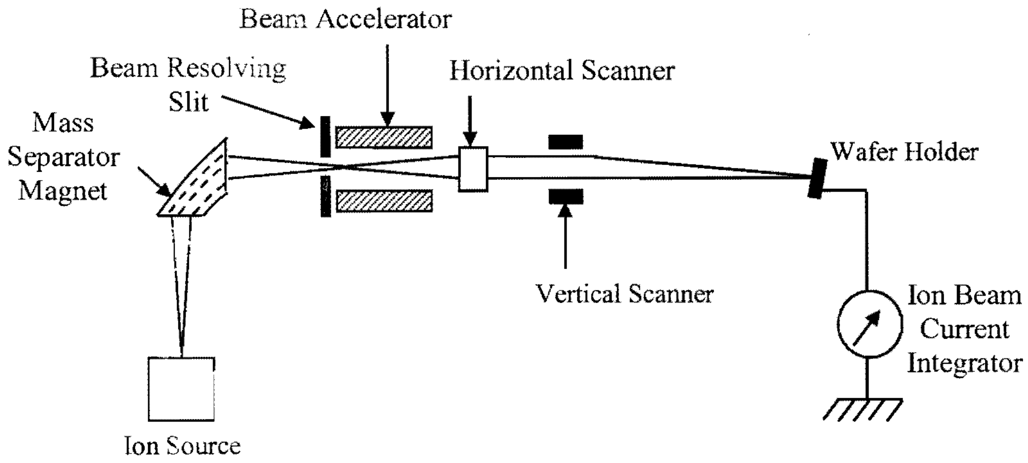

Fig. 4.2

With reference to the components depicted in the figure, briefly describe the sequence of steps involved. (12)

Question Five [25 marks]

(a) An abrupt Si p-n junction has an acceptor concentration $N_a = 1.2 \cdot 10^{18}\,\text{cm}^{-3}$ on one side and a donor concentration $N_d = 1.5 \cdot 10^{16}\,\text{cm}^{-3}$ on the other side.

(i) Calculate the Fermi level positions at 400 ^{o}K in the p and n regions. (4)

(ii) Draw an equilibrium band diagram for the junction and use it to determine the contact potential V_0. (3)

(b) (i) State the implications of a forward bias and reverse bias at a p-n junction. (2)

(ii) Name the two types of transistors that use the above junction properties. (2)

(iii) State one difference between a bipolar junction transistor (BJT) and a field-effect transistor (FET). (2)

(iv) State two general uses of FETs. (2)

(c) Fig. 5.1 shows a three-terminal device in which current flow through two of its terminals is controlled by a voltage at the third terminal.

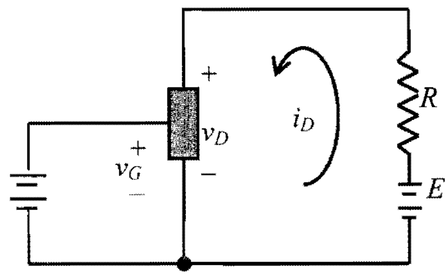

Fig. 5.1

(i) Derive the equation that relates the current i_D and voltage v_D. (2)

(ii) Sketch and label the device I-V characteristics for five sample numerical values of the control voltage v_G. (6)

(iii) Name the solid-state device represented in the figure. (1)

(iv) How can this device be used as switch from an *off* state to an *on* state? (1)

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

Conversion factors	Physical constants	
$1\,\text{eV} = 1.60218 \cdot 10^{-19}\,\text{J}$	Speed of light	$c = 3.00 \cdot 10^{8}\ \text{m/s}$
	Planck's constant	$h = 6.63 \cdot 10^{-34}\ \text{J.s}$
	Boltzmann constant	$k = 1.38 \cdot 10^{-23}\ \text{J/K}$
	Electronic charge	$e = 1.602 \cdot 10^{-19}\ \text{C}$
	Electron mass	$m_e = 9.11 \cdot 10^{-31}\ \text{kg}$
	Proton mass	$m_p = 1.67 \cdot 10^{-27}\ \text{kg}$
	Permittivity of free space	$\varepsilon_0 = 8.8542 \cdot 10^{-12}\ \text{C}^2\text{N}^{-1}\text{m}^{-2}$

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