INDIAN INSTITUTE OF INFORMATION TECHNOLOGY UNA
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School of Electronics
CURRICULUM: IIITUGECE22
End Semester Examination
December 06, 2023
Time: 9:00 AM to 12:00 PM

Degree	B. Tech.	**Branch**	ECE
Semester	VII		
Subject Code & Name	ECPE61: Nanoscience and Nanotechnology		
Time: 180 Minutes	**Answer All Questions**		**Maximum: 100 Marks**

Sl. No.	Question	Marks
1.a	(i) Explain why does a nano-particle tend to have spherical shape by drawing a suitable surface-to-volume versus size of nano-particle, diagram. (ii) Why does 3-D nano material still abbreviated as nanomaterial although none of its three dimensions are **not** confined in nano-matric scale? Justify by drawing suitable diagram. (iii) Mention one electrical property of semiconductor nano-material that changes with dimension.	5 (2+2+1)
1.b	(i) What is meant by a Quantum Well? Describe by drawing the energy band diagram of MOS capacitor, why such Quantum Wells are formed? (ii) For cubical shaped GaAs semiconductor quantum dot, write down the expression for energy of the quantum dot and hence define degenerate energy state. Assuming quantum numbers (n_x , n_y , n_z), draw energy levels as the quantum numbers increase.	5 (3+2)
1.c	(i) What is a surfactant molecule? Give an example surfactant molecule. (ii) Explain the self-assembly of nano-particles by drawing suitable diagram for micelle formation. Mention two factors that govern the self-assembly formation of nano-particles. (iii) Draw field assisted self-assembly for Fe_2O_3 nano-particles.	5 (2+2+1)
1.d	(i) Draw the block diagram of a Scanning Tunneling Microscope (STM) system and explain its operation. (ii) An Atomic Force Microscopy (AFM) system uses a Silicon cantilever beam of dimension 100 μm × 20 μm × 2 μm. The spring constant associated with free vibration of the cantilever, fixed at one end, was found to be k = 0.23 N/m. Calculate the resonance frequency of vibration of the cantilever beam. Given, density of silicon ρ_{Si} = 2.3 g/cm^3.	5 (3+2)

<table>
<tr><td>2.a</td><td>(i) List out all steps involved in a typical sol-gel process to manufacture nano-materials.
(ii) How drying condition determine the formation aerogel and xerogel structures? Mention one technique used to prevent the agglomeration of nano-particles in a colloidal suspension.
(iii) The Point-of-Zero-Charge (PZC) of alumina (Al_2O_3) is 9. Calculate the minimum concentration of OH^- ions (i.e. $[OH^-]$) in the solution, required to coat alumina colloid particle with negative charges in the suspension of ammonium hydroxide. Given rate constant of dissociation of water at 25 °C is, $K_w = 10^{-14}$ (molar)^2.</td><td>5 (2+2+1)</td></tr>
<tr><td>2.b</td><td>(i) Super conducting material Yttrium Barium Copper Oxide (YBCO) are manufactured using solid state reaction method governed by the following reaction
$$\frac{1}{2}Y_2O_3 + 2BaCO_3 + 3CuO \xrightarrow{900^oC} YBa_2Cu_3O_{7-\delta} + 2CO_2$$
Where $\delta \leq 0.2$, calculate the exact weight of Yttrium Oxide (Y_2O_3), Barium Carbonate ($BaCO_3$) and Cupric Oxide (CuO) required synthesize 30 g of YBCO. The atomic mass of the elements are listed in the following table
<table>
<tr><th>Element</th><th>Atomic Mass (g/mol)</th></tr>
<tr><td>Yttrium (Y)</td><td>89</td></tr>
<tr><td>Barium (Ba)</td><td>137</td></tr>
<tr><td>Copper (Cu)</td><td>63.5</td></tr>
<tr><td>Oxygen (O)</td><td>16</td></tr>
</table>
(ii) "Critical temperature of mercury (Hg) is, T_c = 4.2 K" – Explain the statement by drawing suitable graph in the parlance of super conductivity.</td><td>5 (3+2)</td></tr>
<tr><td>2.c</td><td>(i) Describe three growth mechanisms involved during growth of a thin film by drawing suitable diagram. How do these growth mechanisms appear on the cathodoluminescent screen of Reflection High Energy Electron Diffraction (RHEED) window?
(ii) In a Pulsed LASER Deposition (PLD) system, to deposite chromium at 150 °C, calculate the maximum pressure (in mBar) required in the chamber, so that deposition takes place without collision amongst the ionized chromium atoms in plasma. Given, the distance between chromium target and substrate holder is 7 cm, in chamber and atomic radius of chromium atom is 0.13 nm.</td><td>5 (3+2)</td></tr>
<tr><td>2.d</td><td>(i) Define Depth of Focus (DOF) for projection lithography system. Prove that depth of focus is given by,
$$DOF = \pm\frac{\lambda}{2(NA)^2}$$
With help of proper ray diagram and necessary calculations. Where, NA represents the numerical aperture of the lens and λ is wavelength of light used.
(ii) An X-ray exposure system uses photons with energy 5 keV. The separation between mask and wafer is g = 20 μm. Estimate the diffraction limited resolution that is achievable by the system.</td><td>5 (3+2)</td></tr>
<tr><td>3.a</td><td>(i) What is the type of hybridization of carbon atoms that occurs in a carbon nanotube?
(ii) In how many categories carbon nanotubes can be classified? Draw the schematic diagrams for Single Wall Carbon Nano Tube (SWNT) and Multiple Wall Carbon Nano Tube (MWNT)?
(iii) Mention a catalyst used for Chemical Vapour Deposition (CVD) growth on Carbon nanotubes.</td><td>5 (1+3+1)</td></tr>
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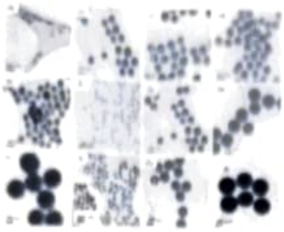
3.b	(i) What is the role of scintillator in a Scanning Electron Microscopy (SEM) system? (ii) Prove that junction depth (x_j) achieved, when a substrate with doping concentration N_B doped using ion implantation process, is given by, $$x_j = R_p + \Delta R_p \sqrt{2ln\left[\frac{N(R_p)}{N_B}\right]}$$ Where the symbols have their usual significance. (iii) An ion implantation system with mass spectrometer has a magnetic analyzer with uniform magnetic flux density B = 400 mT. Ion beam is accelerated using potential energy of 30 keV at the anode of the ion gun. The system is used dope (100) silicon substrate with phosphorus (P) only. But the ion source contains arsenic (As) too as impurity. Calculate the radius at which the slit of magnetic analyzer needs to be placed so that only P ions can pass through, but not the As ions. Given, mass of phosphorus atom m_P = 30 a.m.u., mass of arsenic atom m_{As} = 75 a.m.u., 1 a.m.u. = 1.67377×10^{-27} kg.	5 (1+2+2)
3.c	(i) Which microscopy technique is used to measure surface quality as well as the electrical parameters of substrate? (ii) Draw the Lennard Jones potential /force curve as function of the distance (r) between the centers of two particles. Indicate the portion on the curve at which, AFM measurements are carried out. (iii) Write down two advantages and two disadvantages of Atomic Force Microscopy (AFM).	5 (1+1+3)
3.d	(i) Write down the mechanism by which boron diffuses in a Silicon crystal. (ii) Boron diffusion was carried out using pre-deposition (solid solubility limited) at of 900°C for 30 minutes. Calculate the total dopants incorporated per unit area (Q) of the substrate. Given at 900°C, solid solubility of boron in silicon N_0 = 1.3×10^{20} cm^{-3}, diffusion coefficient of boron in silicon $D = 10^{-15}$ cm^2/s. (iii) If the substrate was initially doped with phosphorous at 1×10^{15} cm^{-3}, what is the junction depth (x_j)? Given, $erfc(3.1633) = 7.692307\times10^{-6}$.	5 (1+2+2)
4.a	(i) Mention three differences between solar cell and a photo detector. (ii) How does efficiency of solar cell vary with band gap of semiconductor material used? Illustrate by drawing suitable efficiency (η) versus band gap (E_g) diagram. (iii) Power delivered by a solar cell is given as, $$P = V\left[I_0 e^{\beta V} - I_{ph}\right]$$ Where $\beta = q/(kT)$. Prove that voltage (V_m) at which maximum power (P_m) is delivered to the load is given by the following equation, $$V_m = \frac{1}{\beta} ln\left[\frac{1+\frac{I_{ph}}{I_0}}{1+\beta V_m}\right]$$	5 (1.5+1.5 +2)
4.b	(i) List out two major application of photonic crystals. (ii) What is the dispersion relation in parlance of a photonic crystal? How photonic bandgap is manifested for photonic crystal? Explain with help of a suitable $\omega - k$ diagram.	5 (1+4)
4.c	(i) Distinguish between 1-D, 2-D, and 3-D photonic crystals by drawing suitable diagrams. Mention one important characteristics of a photonic crystal. (ii) Describe the fabrication process involved to create nanoholes on silicon for implementation of 2-D photonic crystals.	5 (2+3)

4.d	(i) Figure 1 shows the micrograph of an array of silica nanoparticles.  Fig. 1: Electron micrograph of silica nano-paricles. Identify the microscopy technique used to obtain this micrograph. Hence draw its schematic diagram showing all components. (ii) If electron beam was accelerated by applying an energy of 120 keV, calculate de Bröglie wavelength of electrons and comment on the resolution of this microscopy technique. Which material is used as heating filament in an electron gun?	5 (2.5+2.5)
5.a	(i) How anisotropic wet chemical etchants (like KOH, EDP) can be used to fabricate thin silicon membranes for pressure sensing MEMS application, on a (100) silicon wafer? Explain with the help of suitable diagram. (ii) What mask feature size is required to produce a 400 μm × 400 μm diaphragm, having thickness 10 μm from a (100) silicon wafer of thickness 500 μm, using anisotropic etchant KOH.	5 (3+2)
5.b	(i) State three major differences between a classical computer and a quantum computer. (ii) Define bipartite state for 2 given qubits $\lvert q_1\rangle$, $\lvert q_2\rangle$. Hence prove that for quantum 2-qubit CNOT gate, $$CNOT\,\lvert 10\rangle = \lvert 11\rangle$$ Where the symbols have their usual significance.	5 (1.5+3.5)
5.c	(i) Mention two major reasons why $Al_{1-x}Ga_xAs$ / GaAs / $Al_{1-x}Ga_xAs$, Double Heterojunction (DH) LASERs are preferred over GaAs Homojunction LASERs. Explain by drawing suitable energy band diagram. (ii) A GaAs based DH LASER has a Fabry-Perot cavity of Length L = 100 μm. Cleaved faces of GaAs has reflectivities $R_1 = R_2 = 0.32$. If absorption coefficient of GaAs is, $\alpha = 10\ cm^{-1}$ calculate the threshold gain of the cavity required to achieve population inversion.	5 (3+2)
5.d	(i) Write down three differences between a LASER and an LED. (ii) An InGaAs based Avalanche's Photo Diode (APD) with lightly doped *n*-region of length 8 μm has breakdown voltage of V_{BR} = 90 V. Infrared radiation of wavelength λ = 1550 nm and power P_{opt} = 50 mW is allowed to fall on the device. If APD was reverse biased by applying voltage of V = – 8.8 V, calculate the photocurrent generated. Ignore the loss of photons due to absorption by InGaAs. 100.	5 (1.5+3.5)

************* *Best Wishes* *************