Roll No. | | | | |

Internal Assessment Test 2 – Jan 2026

Sub:	Applied Chemistry for Emerging Electronics and Futuristics Device					Sub Code:	1BCHEE102	Branch:	ECE
Date:	06-01-2026	Duration:	90 min's	Max Marks:	50	Sem / Sec:	I / M, N, O & P		OBE

Question no. 1 is COMPULSORY and answer any THREE FULL Questions from the rest.

			MARKS	CO	RBT
1	(a)	What are photovoltaic cells? Explain construction and working of PV cells and mention its 2 advantages.	[7]	CO1	L2
	(b)	What are conducting polymers? Describe synthesis and conducting mechanism of polyaniline and mention its applications for electronic devices.	[7]	CO3	L3
2	(a)	What are Micro electromechanical systems (MEMS) based energy harvesters? Explain their working principle and applications.	[6]	CO1	L2
	(b)	Discuss the difference between organic and inorganic semiconductors.	[6]	CO1	L1
3	(a)	Explain construction and working of ultra-small asymmetric super capacitor and its applications in IoT/wearable devices.	[6]	CO1	L3
	(b)	Discuss synthesis and properties of chitosan-carbon quantum dots hydrogel and its applications in next-generation flexible and wearable electronics.	[6]	CO2	L2
4	(a)	Explain synthesis of TiO_2 nanoparticles by sol-gel method and its uses in sensor applications.	[6]	CO2	L2

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(b)	Explain any 3 size dependent properties of nanomaterials.	[6]	CO2	L2
5(a)	Explain synthesis of Cd-Se Quantum Dots by hot injection method and mention its properties and applications in optoelectronic devices.	[6]	CO2	L2
(b)	Describe synthesis and properties of Graphene Quantum Dots using citric acid method and its applications in emerging electronics.	[6]	CO2	L2
6 (a)	What are Quantum dots (QDs)? Explain optical and electronic properties of quantum dots.	[6]	CO2	L2
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7 (a)	In a sample of a polymer, 100 molecules have the molecular mass 2000 g/mol, 200 molecules have the molecular mass 2000 g/mol, 500 molecules have the molecular mass 10,000 g/mol. Calculate the number average and weight average molecular mass of a polymer.	[6]	CO3	L3
(b)	Discuss basic principle and working of lithography for micro-patterned copper deposition.	[6]	CO3	L2
8 (a)	Explain synthesis and properties PDMS (Polydimethylsiloxane) and discuss its application in RFID.	[6]	CO3	L2
(b)	What is polymer composite? Explain synthesis and properties of epoxy resin-magnetite (Fe_3O_4) composite using ultra-sonication method for sensors applications	[6]	CO3	L2

(Chief Course Instructor) (HOD)

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Internal Assessment Test 2 – J a n 2025

Sub:	Applied Chemistry for Emerging Electronics and Futuristics Device					Sub Code:	1BCHEE102	Branch: ECE
Date:	06-01-2026	Duration:	90 min's	Max Marks:	50	Sem / Sec:	I / M, N, O & P	

Solutions for IAT-2

1 (a) What are photovoltaic cells? Explain construction and working of PV cells and mention its 2 advantages.

A Photovoltaic (PV) cell, also known as a solar cell is a device that converts sunlight (solar energy) directly into electricity using the photovoltaic effect. It is the basic building block of solar panels used in solar energy systems.

Construction

1. Semiconductor Layers:

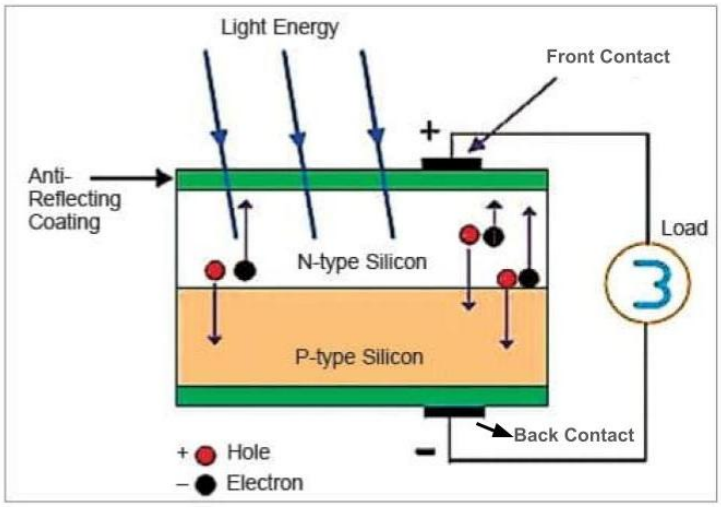
n-type layer: Doped with phosphorus to add extra electrons as upper layer

p-type layer: Doped with boron to create "holes" (positive charge carriers) as bottom layer and these layers form a p-n junction.

2. Front Contact: A thin metal grid on the top surface that allows sunlight to pass through while conducting electricity.

3. Anti-reflective Coating: Reduces reflection and allows more sunlight to be absorbed (TiO_2).

4. Back Contact: A conductive metal layer that completes the electrical circuit.



Working Principle (Photovoltaic Effect):

1. **Diffusion of electrons:** When p-type and n-type silicon layers are joined, electrons from the n-side diffuse into the p-side which initiates the process.

2. **Formation of charge shortage zone and electron–hole pairs:** This diffusion creates a depletion (charge-shortage) region with a built-in electric field. When sunlight (photons) with energy $E=hc/\lambda \geq$

Eg (band gap energy) strikes the junction, electrons in Si are excited from the valence band to the conduction band, generating electron–hole pairs.

3. **Movement of charge carriers and current generation:** The internal electric field drives electrons toward the n-side and holes toward the p-side. When an external load is connected, electrons flow through the circuit to recombine with holes on the p-side, producing electric current.

Advantages

1. Renewable Source: Utilizes abundant solar energy.
2. Environmentally Friendly: No emissions or pollution.
3. Low Operating Cost: Minimal maintenance required.

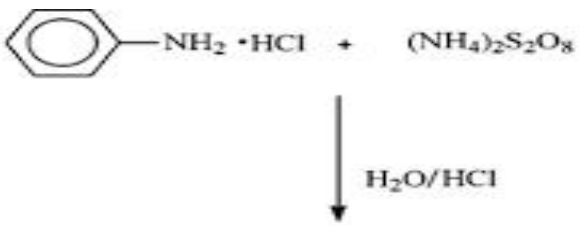
1 (b) What are conducting polymers? Describe synthesis and conducting mechanism of polyaniline and mention its applications for electronic devices.

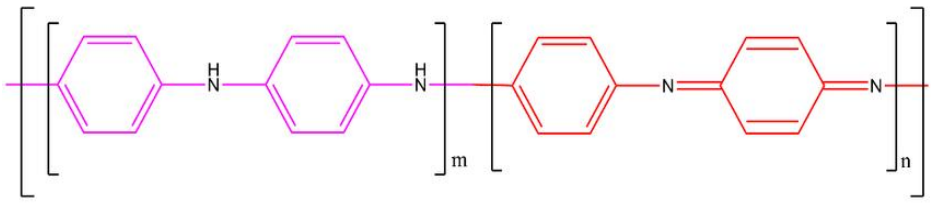
Conducting Polymers: Conducting polymers are a class of organic polymers that can conduct electricity due to the presence of conjugated double bonds (π-electron systems) along their backbone. Unlike conventional polymers (insulators), they combine the mechanical properties of plastics with the electrical properties of metals or semiconductors.

Examples: Polyaniline (PANI), Polypyrrole (PPy), Polyacetylene (PA), Poly(3,4-ethylenedioxythiophene) (PEDOT)

Polyaniline synthesis, conducting mechanism

Polyaniline is synthesized by the **chemical oxidative polymerization** of aniline in acidic medium using ammonium persulfate as the oxidant. The polymer is then filtered, washed, and dried for use.





Emeraldine (partially oxidized ana partially reduced)

P-Type Conducting Mechanism of Polyaniline

Step 1: Protonation of Emeraldine Base: When emeraldine base (EB) is treated with an acid (H^+ A^-), the imine nitrogens get protonated.

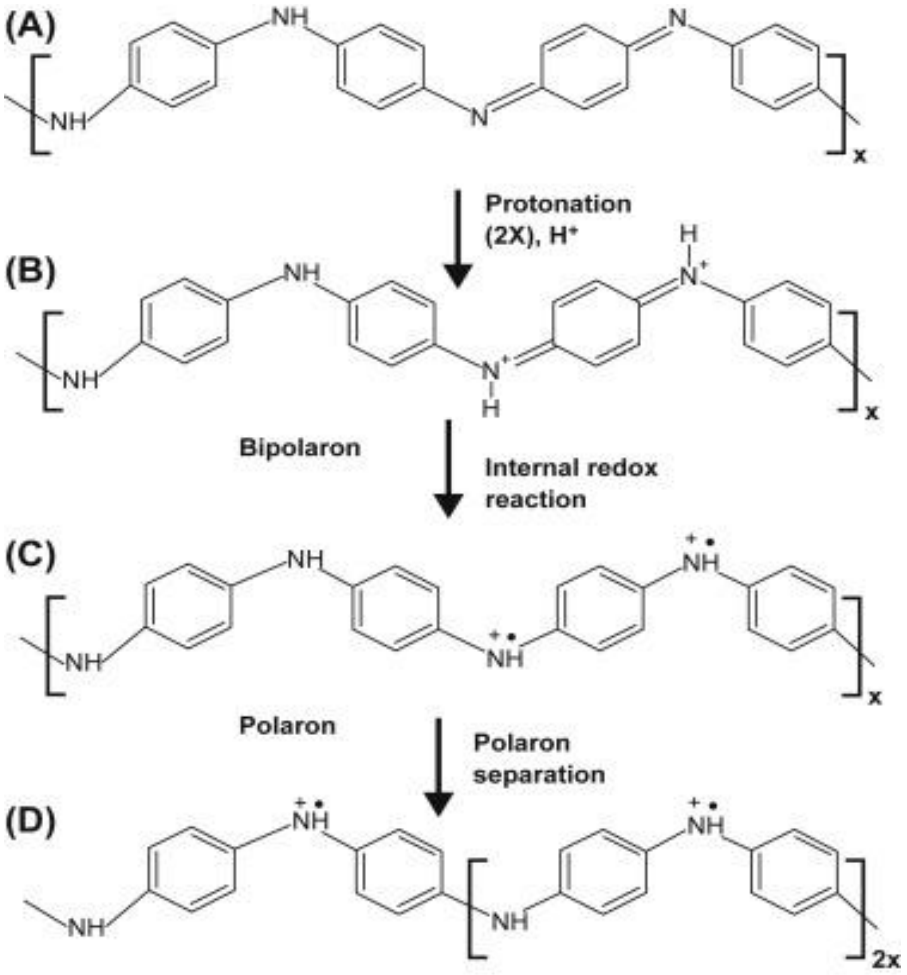
Step 2: Formation of Bipolarons: by losing lone pair of electrons on imine nitrogen results in two polarons and can combine to form a **bipolaron** (dication).

Step 3: Formation of Polarons (Radical Cations): Protonation causes internal electron transfer,

creating a **polaron** (radical cation).

Step 4: Delocalization → Conductivity: Polarons and bipolarons become **delocalized** along the conjugated chain. Delocalized charges move under an electric field → **electrical conductivity**.

Step 5: Formation of Emeraldine Salt (Conducting PANI): Overall, protonation (p-type doping) converts EB into the conducting emeraldine salt (ES).



Applications in electronic devices

1. **Conducting Films and Coatings**: Used in flexible conductive coatings for touch panels, displays, and EMI shielding.
2. **Sensors**: PANI-based gas, chemical, and biosensors due to its conductivity changes with environment.
3. **Supercapacitors and Batteries**: Acts as an electrode material in energy storage devices because of high capacitance and stability.
4. **Organic LEDs (OLEDs)**: Used as a hole transport layer in organic light-emitting devices.
5. **Flexible and Wearable Electronics**: PANI's flexibility and conductivity make it suitable for stretchable circuits, e-skin, and wearable sensors.

2 (a) What are Micro electromechanical systems (MEMS) based energy harvesters? Explain their working principle and applications.

Micro Electromechanical Systems (MEMS)-based energy harvesters are miniature devices that convert ambient mechanical energy (such as vibrations, motion, or pressure) into electrical energy using microfabricated components. They are designed to power small electronic devices or sensors without external batteries, making them ideal for IoT and wireless sensor networks.

The three main types of MEMS-based energy harvesters are:

1. Piezoelectric Energy Harvesters
2. Electromagnetic Energy Harvesters
3. Electrostatic (Capacitive) Energy Harvesters

Construction:

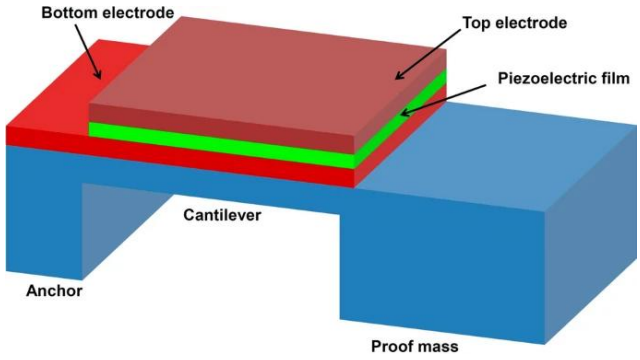
A **piezoelectric energy harvester** consists of:

A **piezoelectric material** (like PZT Lead Zirconate Titanate, with the chemical formula $Pb(Zr_xTi_{1-x})O_3$, ZnO, or PVDF) coated on a **substrate or cantilever beam which is made up off Si or SiO_2**.

A **proof mass** attached at the free end to enhance vibration response.

Electrodes (Pt films about 100 nm) on both sides of the piezoelectric layer to collect generated charge.

It is usually fabricated using **MEMS techniques** for compact size and high sensitivity.



Piezoelectric Energy Harvesters Working Mechanism:

1. When a piezoelectric MEMS device is subjected to mechanical vibration or acceleration, the cantilever structure undergoes bending, which induces mechanical strain in the attached piezoelectric layer.
2. Because of the non-centrosymmetric crystal structure of the piezoelectric material, this strain causes a displacement of positive and negative charge centers within the crystal lattice.
3. Consequently, charges accumulate on the top and bottom electrodes, generating a voltage (potential difference) across them.

4. This voltage can be harnessed by an external circuit, either to store energy in capacitors or batteries or to directly power small electronic devices such as sensors or wearable electronics.

5. Piezoelectric MEMS energy harvesters thus efficiently convert mechanical energy into usable electrical energy at the microscale.

Applications of MEMS-Based Energy Harvesters:

1. Wireless Sensor Networks (WSNs): Powering sensors in structural health monitoring, agriculture, and industrial automation. Eliminates the need for battery replacement in remote locations.

2. Wearable Electronics: Harvesting energy from body movements to power health-monitoring devices. Examples: Fitness trackers, smartwatches, medical implants.

3. Internet of Things (IoT): Self-sustaining sensors and devices in smart homes and cities. Enhances deployment flexibility and reduces maintenance.

4. Biomedical Devices: Powering pacemakers or drug delivery systems using body motion or temperature differences. Reduces or eliminates the need for surgical battery replacement.

2(b) **Discuss the difference between organic and inorganic semiconductors.**

Feature	Organic Semiconductors	Inorganic Semiconductors
Composition	Made of carbon-based molecules or polymers with conjugated π-bonds.	Made of pure elements or compounds like Si, Ge, GaAs.
Structure & Bonding	Molecular or polymeric, with van der Waals interactions between molecules.	Crystalline lattice, strong covalent or ionic bonding.
Processing & Cost	Can be solution-processed or printed, often low-cost fabrication.	Requires high-temperature, complex crystal growth, expensive fabrication.
Flexibility	Highly flexible, suitable for bendable devices.	Rigid and brittle, not suitable for flexible electronics.
Mobility	Moderate to low charge carrier mobility (10^{-3} – 1 cm²/V·s).	High mobility (100–1500 cm²/V·s), efficient charge transport.
Stability	Lower chemical and thermal stability, sensitive to air/light.	High chemical and thermal stability, durable in ambient conditions.
Applications	Flexible displays, OLEDs, OFETs, organic solar cells.	Traditional electronics: transistors, diodes, solar cells, microchips.
Energy Band Gap	Generally larger band gaps (~1.5–3 eV), tunable via chemical modification.	Typically smaller band gaps (~0.6–1.5 eV), fixed by crystal structure.
Environmental Impact	Often eco-friendly and biodegradable depending on material.	Can be toxic or non-biodegradable, environmental disposal is a concern.

3 (a) Explain construction and working of ultra-small asymmetric super capacitor and its applications in IoT/wearable devices.

An ultra-small asymmetric supercapacitor (ASC) is a miniaturized energy storage device that combines two different types of electrode materials: One behaving like a battery electrode (faradaic, pseudocapacitive, high capacity).

Construction

Anode (EDLC Electrode): high surface area, good electrical conductive materials like activated carbon, CNTs, graphene

Cathode (Pseudocapacitive Electrode): metal oxides like MnO_2, RuO_2

Electrolyte: contains positive and negative ions which can freely movable between electrodes like KOH, H_2SO_4 and ionic liquids

Separator: A thin porous polymer film (cellulose paper). Prevents electrical contact between electrodes but allows ion flow.

Current Collectors: Copper foil or aluminum foil (both sides).

Encapsulation: Protective flexible packaging to ensure safety, biocompatibility, and durability.

Working Principle:

(a) During Discharging (energy release):

Activated carbon stores charge via an electric double layer, and during discharge electrons flow out while K^+ ions diffuse back into the electrolyte to maintain neutrality. MnO_2 gets reduced by accepting electrons from the external circuit, and simultaneously K^+ ions insert into its lattice. Thus, AC releases stored charge electrostatically while MnO_2 undergoes redox with ion insertion to balance charge.

At the anode (Activated Carbon): $C^- . K^+_{(adsorbed)} \rightarrow C + e- + K^+_{(solution)}$

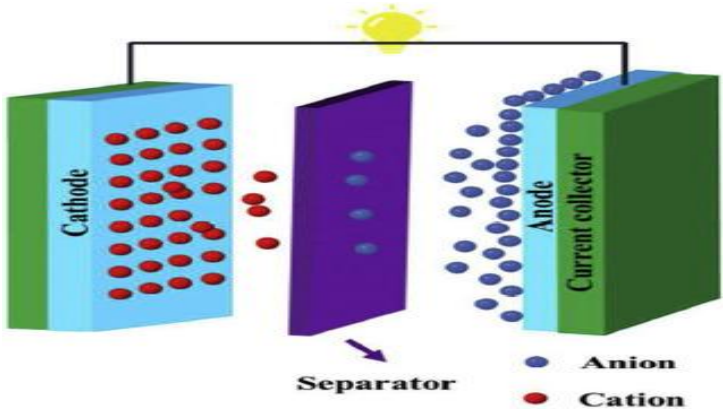
Reduction reaction: $MnO_2 + K^+ + e- \rightarrow KMnO_2$

(b) During Charging (energy storage):

Electrons are withdrawn by the power source, causing $KMnO_2$ to undergo oxidation and release the inserted K^+ ions back into the electrolyte. The AC electrode receives electrons at the negative terminal, and cations from the electrolyte migrate toward its negatively charged surface to maintain charge neutrality and form an electric double layer.

At the cathode: $KMnO_2 \rightarrow MnO_2 + K^+ + e-$

At the anode (Activated Carbon): $C + e- + K^+_{(solution)} \rightarrow C^- . K^+_{(adsorbed)}$



Applications:

1. Wireless Sensor Networks (WSNs): Provide stable, rapid power for intermittently operating IoT sensors. Enable energy harvesting from solar, vibration, or RF sources to support continuous IoT node operation.

2. Smart Home Devices: Used in ultra-small sensors (temperature, humidity, motion, gas). Quick recharge allows reliable operation of always-on IoT devices.

Smart Wearables: Powering smartwatches, fitness trackers, smart rings, AR/VR glasses. Provide quick charge and discharge to support wireless communication (Bluetooth, Wi-Fi).

2. Electronic Textiles (E-textiles): Embedded into fabrics as flexible energy storage units. Useful for military uniforms, smart clothing, and fashion tech with LEDs or sensors.

3 (b) **Discuss synthesis and properties of chitosan-carbon quantum dots hydrogel and its applications in next-generation flexible and wearable electronics.**

Step-by-step synthesis of a chitosan–carbon-quantum-dot (CQD) hydrogel

1. **Make carbon quantum dots (CQDs):** Dissolve citric acid and urea in water, transfer to a Teflon-lined autoclave, hydrothermal 160–200 °C, 2–6 h. Cool and dialyze/filter to get CQDs (2–8 nm) with surface functionalization of –COOH/–OH/–NH_2 .

$$C_6H_8O_7 \xrightarrow[\text{hydrothermal}]{\Delta} \text{CQDs} + CO_2 + H_2O$$

2. Prepare chitosan solution: Disperse chitosan powder in an acetic solution, such as glacial acetic acid to make it soluble and stir the mixture for several hours to obtain a homogenous, viscous solution which forms the basis of the hydrogel.

3. Disperse CQDs in chitosan: Carbon quantum dots (CQDs) can be dispersed in a chitosan solution, followed by adding glutaraldehyde as a crosslinker. The aldehyde groups react with amino groups of chitosan through Schiff-base formation (-C=N-), embedding CQDs within the hydrogel matrix. This yields a stable, fluorescent CQDs–chitosan hydrogel network.

$$\text{Chitosan–}NH_2 + OHC\text{–}(CH_2)_3\text{–}CHO \rightarrow \text{Chitosan–N=CH–}(CH_2)_3\text{–CH=N–Chitosan}$$

(crosslinked, with CQDs embedded).

4) Set, wash, and store: Allow gel to set (30–60 min), then wash with water to remove excess small molecules (acetic acid, TPP, by-products). Store hydrated; the gel shows blue/green fluorescence under UV due to embedded CQDs.

Properties:

1. Biocompatible: Made from natural chitosan and non-toxic carbon dots, making it safe for drug delivery and wound healing.
2. Fluorescent: CQDs give strong blue/green photoluminescence under UV light, useful for imaging and sensing.
3. High Water Absorption: The porous 3D network absorbs large amounts of water, giving good swelling and tissue-like softness.
4. Good Mechanical Strength: Crosslinking provides flexibility and elasticity, helping the gel bend or stretch without breaking.

Applications

1. **Flexible Biosensors**: Used for glucose, lactate, and sweat sensing because the hydrogel absorbs body fluids and CQDs give clear fluorescence/electrochemical signals.
2. **Wearable Health Monitors**: Used in wearable patches to monitor heart rate, hydration, and stress due to their conductivity and skin-friendly nature.
3. **Smart Wound Dressings**: Detect infection (pH/bacteria) and support faster healing with chitosan's natural antibacterial properties.
4. **Stretchable Electrodes**: Work as soft, bendable electrodes for electronic skin and flexible circuits without losing conductivity.

4 (a) Explain synthesis of TiO_2 nanoparticles by sol-gel method and its uses in sensor applications.

Synthesis of TiO_2 Nanoparticles by Sol-Gel method for sensor applications

The sol-gel method is a popular technique for synthesizing TiO_2 nanoparticles. It involves a series of chemical reactions, starting with the hydrolysis of a titanium precursor (metal alkoxides), followed by condensation to form a gel, and finally, calcination to obtain the desired TiO_2 nanoparticles. This method allows for the control of particle size, morphology, and crystallinity by adjusting various parameters.

1. Precursor Selection: Titanium tetraisopropoxide (TTIP) $Ti[OCH(CH_3)_2]_4$ or titanium butoxide $Ti(OBu)_4$ are commonly used precursors.

2. Hydrolysis (sol formation): The precursor is dissolved in a solvent (like methanol or isopropanol) and then hydrolyzed by adding water, often with an acid (HNO_3). The alkoxide groups (–OR) are partially or completely replaced by hydroxyl groups (–OH).

For titanium isopropoxide (R = $–CH(CH_3)_2$):

$Ti[OR]_4 + 4H_2O \rightarrow Ti(OH)_4 + 4\ ROH$

3. Gelation: Transfer the sol to a sealed container (parafilm or PTFE-lined cap) and age 12–24 h at room temp (or 40 °C for 4–6 h). The hydrolyzed precursor undergoes condensation reactions, forming Ti-O-Ti bonds and creating an oxide network structure, which leads to the formation of a 3D gel.

(a) Water condensation: $Ti–OH + HO–Ti \rightarrow Ti–O–Ti + H_2O$

(b) Alcohol condensation: $Ti–OR + HO–Ti \rightarrow Ti–O–Ti + ROH$

Together, these condensation reactions build up a polymeric Ti–O–Ti gel network.

4. Drying and Calcination: The wet gel is dried at 60–80 °C overnight (either in air or under vacuum) to remove the solvent, resulting in either a xerogel or an aerogel. The dried material is then calcined at a high temperature (e.g., 300-800°C) for 4h to remove organic residues and further crystallize the TiO_2.

Applications of TiO_2 nanoparticles in sensor development:

- Gas Sensors: TiO_2 NPs detect gases like H_2, CO, NO_2, and O_2 due to their high surface area and strong surface adsorption properties.
- Humidity Sensors: Their hydrophilic surface makes TiO_2 ideal for measuring relative humidity through resistance or capacitance changes.
- Biosensors: TiO_2 NPs act as biocompatible platforms for enzyme or DNA immobilization, enabling glucose, cholesterol, and pathogen detection.
- UV/Optical Sensors: Because of their wide bandgap and strong UV absorption, TiO_2 is used in UV photodetectors and optical switches.
- Electrochemical Sensors: TiO_2 nanoparticle-modified electrodes enhance electron transfer for detecting metal ions, pollutants, and biomolecules.

4(b) **Explain any 3 size dependent properties of nanomaterials.**

Size-dependent properties of nanomaterials

The properties of nanomaterials differ significantly from their bulk counterparts because size reduction to the nanometer regime (1–100 nm) introduces quantum effects and drastically increases the surface-to-volume ratio.

1. Surface Area-Dependent Properties

When the particle size decreases to the nanoscale, the surface-to-volume ratio increases dramatically. A greater proportion of atoms resides on the surface compared to the bulk, meaning surface phenomena dominate and result in higher surface energy, enhanced adsorption capacity, and increased reactivity (chemical, electrochemical, catalytic).

Examples: TiO_2 nanoparticles (used in photocatalysis): Smaller TiO_2 nanoparticles (~10 nm) show

higher degradation efficiency of dyes and pollutants compared to larger ones because more active sites are exposed.

2. Catalytic Properties

Catalysis relies heavily on the number and accessibility of active sites. Nanosized catalysts expose a greater number of surface atoms and often have unsaturated coordination or defect sites that enhance their activity.

Examples: Gold nanoparticles (Au NPs): Bulk gold is inert, but Au nanoparticles (<5 nm) become highly catalytic. For instance, Au NPs supported on TiO_2 catalyze CO oxidation at low temperatures.

3. Electrical Properties

At the nanoscale, electrons are confined within extremely small dimensions. This leads to quantum confinement effects that result in discrete energy levels (instead of continuous bands in bulk), size-dependent band gap variation and altered charge transport behavior.

Examples: Single-walled carbon nanotubes (SWCNTs): Depending on their chirality and diameter, they can behave as metallic or semiconducting, making them useful in nanoscale transistors and interconnects.

5(a) **Explain synthesis of Cd-Se Quantum Dots by hot injection method and mention its properties and applications in optoelectronic devices.**

Cadmium selenide (CdSe) quantum dots are very tiny semiconductor nanoparticles (only a few nanometers in size). Because of their small size, they show the quantum confinement effect — their color and optical properties depend directly on their particle size. Smaller dots glow in blue/green, while larger dots glow in orange/red.

Step-by-step procedure for the synthesis of CdSe QDs using hot injection method

1. Preparation of Cadmium Precursor Complex: When CdO is used as precursor, it is dissolved in a fatty acid such as stearic acid (R–COOH) or oleic acid at high temperature to form cadmium stearate/oleate.

$$CdO + 2R\text{–}COOH \xrightarrow{\Delta} Cd(R\text{–}COO)_2 + H_2O$$

This gives a soluble cadmium complex coordinated with long-chain ligands.

2. Formation of Selenium Precursor: Elemental selenium (Se) is insoluble in nonpolar solvents, so it is dissolved in trioctylphosphine (TOP) to make TOPSe under intert gas. This keeps selenium reactive and soluble until injection.

$$Se(s) + TOP \longrightarrow TOPSe$$

3. Hot Injection (Nucleation Step): At high temperature (≈ 280–320 °C), the selenium precursor (TOPSe) is swiftly injected into the hot cadmium complex solution. The reaction produces cadmium selenide (CdSe) nuclei and this step is very fast and undergoes an intense nucleation event, leading to burst nucleation.

$$Cd(R\text{–}COO)_2 + TOPSe \xrightarrow{\Delta} CdSe\downarrow + \text{byproducts (TOP, R–COOH)}$$

4. Quench, purify and stabilize: Quench by cooling and adding a solvent/ligand (e.g., toluene + oleic acid). Purify by precipitation (ethanol/acetone) and centrifugation; redissolve in nonpolar solvent. Surface ligands ($RCOO^-$) cap QDs, stabilizing them: $CdSe{\cdot}(RCOO)_2$.

Applications in optoelectronic devices

CdSe quantum dots (QDs) are tiny semiconductor nanocrystals with size-dependent optical and electrical properties. Because of their tunable bandgap and bright light emission, they are widely used in optoelectronic devices. Their main applications are:

1. Light-Emitting Diodes (LEDs): CdSe QDs are used in QD-LEDs to produce bright and pure colors. The color can be changed by controlling the size of the quantum dots.

2. Solar Cells: They are used in quantum dot-sensitized solar cells to absorb sunlight efficiently. Since their bandgap is tunable, they can capture more of the solar spectrum and improve energy conversion.

3. Photodetectors: CdSe QDs are used to make photodetectors that can sense UV, visible, or near-infrared light. They are sensitive and have a fast response.

4. Displays and TVs: CdSe QDs are used in modern displays (QD-LCDs and QD-OLEDs) to generate pure red and green colors, giving better picture quality and wider color range.

5. Optical Sensors: CdSe QDs can act as sensors because their fluorescence changes when they interact with gases or biomolecules.

5(b) **Describe synthesis and properties of Graphene Quantum Dots using citric acid method and its applications in emerging electronics.**

Graphene Quantum Dots (GQDs) are nanoscale fragments of graphene with strong quantum confinement and edge effects. They exhibit excellent photoluminescence, high surface area, biocompatibility, and chemical stability. Their tunable optical and electronic properties make them useful in bioimaging, sensors, energy devices, and optoelectronics.

synthesis of GQDs from citric-acid (bottom-up)

1) Nucleation of GQDs by Melt and carbonize the citric acid

When citric acid is heated to about 160 °C for 10 minutes and further heated at 180–200 °C for 15 minutes changes the color from yellow to orange and then to brown. This indicates dehydration and decarboxylation reactions, leading to the formation of tiny sp^2 carbon nuclei that become the cores of graphene quantum dots (GQDs).

Dehydration & condensation:

$$\text{citric acid} \xrightarrow{\Delta} \text{poly(anhydride)/carbonized intermediates} + H_2O$$

Decarboxylation & aromatization → sp² domains (GQD cores):

$$\text{(intermediates)} \xrightarrow{\Delta} \text{GQD } (sp^2\text{-C}) + CO_2 + H_2O$$

2) Quench and neutralize (stop growth; make dots water-dispersible)

After heating citric acid, the solution is cooled and treated with warm NaOH (0.5–1 M) under stirring until the pH reaches 7–8. This step stops further carbonization and prevents the growth of larger particles. The –COOH groups on the carbon dot edges are deprotonated to $–COO^-$, making the graphene quantum dots stable, soluble, and brightly fluorescent.

Neutralization at the edges:

$$R{-}COOH \text{ (GQD edge)} + NaOH \rightarrow R{-}COO^-Na^+ + H_2O$$

3) N-doping / surface passivation (brighter PL, different color)

In the synthesis of graphene quantum dots, adding ethylenediamine (EDA) or urea followed by mild heating (80–120 °C) helps in forming amide or imine linkages at the edges. This process introduces nitrogen atoms into the GQDs, known as nitrogen doping. Nitrogen doping improves surface properties and causes a shift in fluorescence emission.

Edge coupling (schematic amidation):

$$R{-}COOH + H_2N{-}CH_2CH_2{-}NH_2 \rightarrow R{-}CO{-}NH{-}CH_2CH_2{-}NH_2 + H_2O$$

4) Purify

After synthesis, the solution is first filtered (0.22 μm) to remove large particles and then dialyzed for 24–48 hours in water to purify it. This gives a clear solution of graphene quantum dots (GQDs) that glows blue or green under UV light. The GQDs can be stored at room temperature or 4 °C. Their size (2–10 nm) and properties are usually checked by UV–Vis, photoluminescence, and electron microscopy.

Applications of Graphene Quantum Dots (GQDs) in Emerging Electronics

1. **LEDs:** GQDs show strong, tunable fluorescence, making them useful in efficient blue, green, and white LED fabrication.
2. **Solar Cells:** GQDs provide broad light absorption and fast electron transfer, improving photovoltaic efficiency.
3. **Flexible Displays:** High luminescence and nanoscale size allow GQDs to be used in thin, bendable display panels.

4. **Transistors:** GQDs enhance electrical conductivity and charge mobility in thin-film transistor devices.
5. **Sensors:** GQDs show fluorescence changes on analyte interaction, enabling sensitive gas, ion, and biomolecule sensing.
6. **Supercapacitors:** GQDs increase electrode surface area and conductivity, boosting energy storage performance.

6 (a) **What are Quantum dots (QDs)? Explain optical and electronic properties of quantum dots.**

Quantum dots (QDs) are semiconductor nanocrystals typically ranging from 2–10 nm, whose unique properties arise from quantum confinement effects.

Optical and electronic properties of quantum dots

Quantum dots (QDs) exhibit remarkable optical and electronic properties due to quantum confinement—where charge carriers (electrons and holes) are confined in all three spatial dimensions.

Optical Properties

1. **Size-dependent emission:** The colour of light emitted by QDs changes with their size — smaller QDs emit blue light, and larger QDs emit red light.
2. **Narrow emission spectrum:** QDs emit very sharp and narrow peaks of light, giving pure and bright colours.
3. **Broad absorption spectrum:** They can absorb a wide range of wavelengths, making them good for solar cells and LEDs.
4. **High photoluminescence efficiency:** QDs convert absorbed light into emitted light very efficiently.
5. **Tunable band gap:** By changing the size or composition of QDs, their band gap can be adjusted easily.

Electronic Properties

1. **Quantum Confinement Effect**: When the size of QDs becomes very small (below ~10 nm), the movement of electrons is restricted, which changes their energy levels.
2. **Discrete Energy Levels (Atom-like States):**
   Because of their tiny size, QDs show **separate (quantized) energy levels** instead of continuous bands, making them behave like artificial atoms.
3. **High Charge Carrier Mobility:** QDs can transfer electrons and holes efficiently due to their tunable surface and band structure, improving their electronic performance.
4. **Tunable Conductivity:** By changing size, shape, or surface ligands, the electrical conductivity of QDs can be increased or decreased as required.

6(b) **Explain synthesis and properties of Polyvinylidene Fluoride (PVDF) and its applications in E-nose devices**

Polyvinylidene fluoride (PVDF) is a high-performance semicrystalline fluoropolymer with the chemical formula $(–CH_2–CF_2–)_n$. It is known for its high chemical resistance, thermal stability, mechanical strength, and piezoelectric properties, making it widely used in electronics, sensors, membranes, and

energy devices.

Synthesis: PVDF is synthesized primarily through free-radical polymerization of vinylidene fluoride ($CH_2=CF_2$) monomers:

1. **Monomer**: Vinylidene fluoride ($CH_2=CF_2$)

2. **Initiator:** Free-radical initiators such as peroxides or azo compounds

$$R–O–O–R \xrightarrow{\Delta} 2R^{\cdot}$$

3. **Process**: The monomer undergoes radical polymerization under controlled temperature and pressure. Chain propagation forms $–CH_2–CF_2–$ repeating units.

$$R^{\cdot} + CH_2=CF_2 \longrightarrow R–CH_2–CF_2^{\cdot}$$

Propagation: $R–(CH_2–CF_2)_m–CF_2^{\cdot} + CH_2=CF_2 \longrightarrow R–(CH_2–CF_2)_{m+1}–CF_2^{\cdot}$

Termination — combination

$$R–(CH_2–CF_2)_{m+1}–CF_2^{\cdot} + R–(CH_2–CF_2)_{m+1}–CF_2^{\cdot} \longrightarrow R–(PVDF)–(PVDF)–R$$

4. **Outcome**: Produces PVDF in different forms, including homopolymer films, fibers, or powders, which can be processed further for membranes or electronic applications.

$$nCH_2=CF_2 \xrightarrow{\text{Initiator}} (–CH_2–CF_2–)_n$$

Properties of PVDF:

1. Mechanical properties: High tensile strength, flexibility, and impact resistance.
2. Thermal stability: Stable up to ~170–175°C.
3. Chemical resistance: Resistant to acids, bases, solvents, and UV radiation.
4. Electrical properties: Dielectric, piezoelectric, and ferroelectric characteristics.
5. Processability: Can be fabricated into films, fibers, coatings, membranes, and composites.
6. Hydrophobicity: Low surface energy, water-resistant, and self-cleaning surfaces.

Applications in E-nose devices.

1. Used as a **sensitive sensing layer** for detecting gases and VOCs.
2. Acts as a **piezoelectric transducer**, converting gas interaction into electrical signals.
3. Enables **odor and gas discrimination** in sensor arrays.
4. Used in **wearable and flexible E-nose devices** due to high flexibility.
5. Suitable for **breath-analysis E-noses** for medical diagnostics.
6. Works in **industrial E-noses** for pollution and hazardous gas monitoring due to chemical stability.

7 (a) **In a sample of a polymer, 100 molecules have the molecular mass 2000 g/mol, 200 molecules have the molecular mass 2000 g/mol, 500 molecules have the molecular mass 10,000 g/mol. Calculate the number average and weight average molecular mass of a polymer.**

Number-average molecular mass (M_n)

$$M_n = \frac{\sum N_i M_i}{\sum N_i}$$

$$\sum N_i M_i = (300 \times 2000) + (500 \times 10{,}000)$$

$$= 600{,}000 + 5{,}000{,}000 = 5{,}600{,}000$$

$$M_n = \frac{5{,}600{,}000}{800} = \boxed{7000\ \text{g/mol}}$$

2 Weight-average molecular mass (M_w)

$$M_w = \frac{\sum N_i M_i^2}{\sum N_i M_i}$$

Calculate numerator:

$$\sum N_i M_i^2 = (300 \times 2000^2) + (500 \times 10{,}000^2)$$

$$= 300 \times 4 \times 10^6 + 500 \times 1 \times 10^8$$

$$= 1.2 \times 10^9 + 5.0 \times 10^{10} = 5.12 \times 10^{10}$$

Denominator:

$$\sum N_i M_i = 5.6 \times 10^6$$

$$M_w = \frac{5.12 \times 10^{10}}{5.6 \times 10^6} = \boxed{9.14 \times 10^3\ \text{g/mol}}$$

$$M_w \approx \boxed{9140\ \text{g/mol}}$$

7(b) **Discuss basic principle and working of lithography for micro-patterned copper deposition.**

Principle: Lithography is a pattern-transfer technique used to create very small, precise structures on a surface. It is one of the most important processes in microelectronics, semiconductor manufacturing, MEMS, nanotechnology, and material science.

Working / Process Steps

1. Substrate Cleaning: Silicon wafer is thoroughly cleaned using solvents like acetone, IPA, and DI water. Removes dust, grease, and organic contaminants to improve film adhesion.

2. Metal Deposition: A thin **adhesion layer** (Ti or Cr, typically 10–20 nm) is deposited using sputtering or thermal evaporation. A **copper film** (100–500 nm) is deposited over the adhesion layer. Ti/Cr is used because Cu alone does not bond strongly to Si/SiO_2 .

3. Spin-Coating Photoresist: Liquid photoresist is dropped onto the wafer and spun at high speed (2000–4000 rpm) which creates a uniform thin resist layer. Thickness depends on application (1–10 μm).

4. Soft Bake (Pre-bake): Wafer is heated on a hot plate (90–100 °C for ~1–2 min) which removes remaining solvent and improves adhesion.

5. UV Exposure Through Mask: The wafer is aligned under a **photomask** that contains the micropattern design. UV light selectively exposes areas of the photoresist.

- For **positive resist**: exposed regions become soluble.
- For **negative resist**: exposed regions become cross-linked and insoluble.

6. Development: Wafer is dipped into developer solution to remove the soluble part of the resist, revealing Cu beneath in patterned areas on the wafer.

7. Copper Etching: Wet etchant (e.g., ferric chloride $FeCl_3$ or ammonium persulfate) removes Cu only in exposed regions. Protected Cu under resist remains intact.

8. Photoresist Stripping: Acetone or plasma cleaning removes the remaining resist which results in precise copper micropatterns remain on the substrate.

Lithography-based copper micro-patterning is a key technique in microelectronics for fabricating

interconnects, integrated circuits, MEMS devices, sensors, and printed electronic components. It provides high precision, repeatability, and compatibility with large-scale production.

8 (a) Explain synthesis and properties PDMS (Polydimethylsiloxane) and discuss its application in RFID.

Polydimethylsiloxane (PDMS) is a widely used silicon-based organic polymer belonging to the silicone family. It is known for its excellent flexibility, transparency, biocompatibility, and chemical stability. PDMS is commonly used in microfluidics, soft lithography, biomedical devices, and wearable electronics due to its elastic and soft rubber-like behavior.

Synthesis: PDMS is synthesized mainly through two major steps: formation of siloxane monomers and polymerization to form long silicone chains, followed by cross-linking to create an elastomer.

Step 1: Formation of Siloxane Monomers: Dimethyldichlorosilane $Si(CH_3)_2Cl_2$ undergoes hydrolysis with water, it forms dimethylsiloxane units and releases HCl.

$Si(CH_3)_2Cl_2 + 2H_2O \rightarrow HO–Si(CH_3)_2–OH + 2HCl$

These hydroxyl-terminated units then undergo condensation reactions, forming siloxane (Si–O–Si) bonds, producing cyclic monomers or linear siloxane chains.

Step 2: Polymerization: The cyclic siloxane monomers undergo ring-opening polymerization using acid or base catalysts, producing long PDMS polymer chains of controlled molecular weight.

Step 3: Cross-linking (Curing): To convert liquid PDMS into solid elastomer, cross-linking is performed using platinum-catalyzed hydrosilylation curing. This step joins polymer chains into a 3-D network, producing soft, rubber-like PDMS used in microfabrication.

Applications in RFID (Radio Frequency Identification)

1. Used as a flexible substrate for printed RFID antennas and circuits.
2. Acts as a protective encapsulation layer, shielding components from moisture, corrosion, and mechanical damage.
3. Exhibits good dielectric properties, improving antenna efficiency and wireless communication range.
4. Enables wearable RFID tags for healthcare monitoring and smart garments.
5. Used in smart packaging and logistics tracking labels.
6. Suitable for e-textiles and flexible IoT devices and in implantable RFID systems due to its biocompatibility.

8 (b) What is polymer composite? Explain synthesis and properties of epoxy resin-magnetite (Fe_3O_4) composite using ultra-sonication method for sensors applications

Polymer composites are materials formed by combining a polymer matrix with reinforcing fillers such as fibers, nanoparticles, or flakes to improve mechanical, thermal, and electrical properties.

Synthesis:

1. **Preparation of Fe_3O_4 NPs**: Iron oxide nanoparticles are produced by adding Fe^{2+} /Fe^{3+} salt solution to an alkaline medium, which precipitates Fe_3O_4 instantly. The nanoparticles are then washed, separated, and stabilized to avoid agglomeration.

2. **Prepare nanoparticle dispersion:** Weigh Fe_3O_4 NPs (typical loading 1–20 wt% relative to epoxy) and disperse in small volume of solvent to make a slurry.

3. **Ultrasonication:** Sonicate the Fe_3O_4 slurry using a probe or bath sonicator at moderate power (e.g., 100–300 W probe) for 10–30 minutes with pulse mode (e.g., 10 s on / 5 s off) and cooling (ice bath) to avoid overheating. This breaks agglomerates and yields a uniform dispersion.

4. **Mix with epoxy resin:** Add the sonicated dispersion to the epoxy resin (base) and stir mechanically for 10–20 min to maintain homogeneity.

5. **Degassing:** Place the mixture in a vacuum desiccator (≈10–30 min) to remove entrapped air and solvent.

6. **Casting and curing:** Pour the composite into molds. Cure at room temperature for primary set (typical 24 h), then post-cure at elevated temperature (e.g., 60–80 °C for 2–4 h) to complete crosslinking.

Properties:

1. **High mechanical strength**: Fe_3O_4 nanoparticles reinforce the epoxy matrix, improving tensile, compressive, and impact strength.

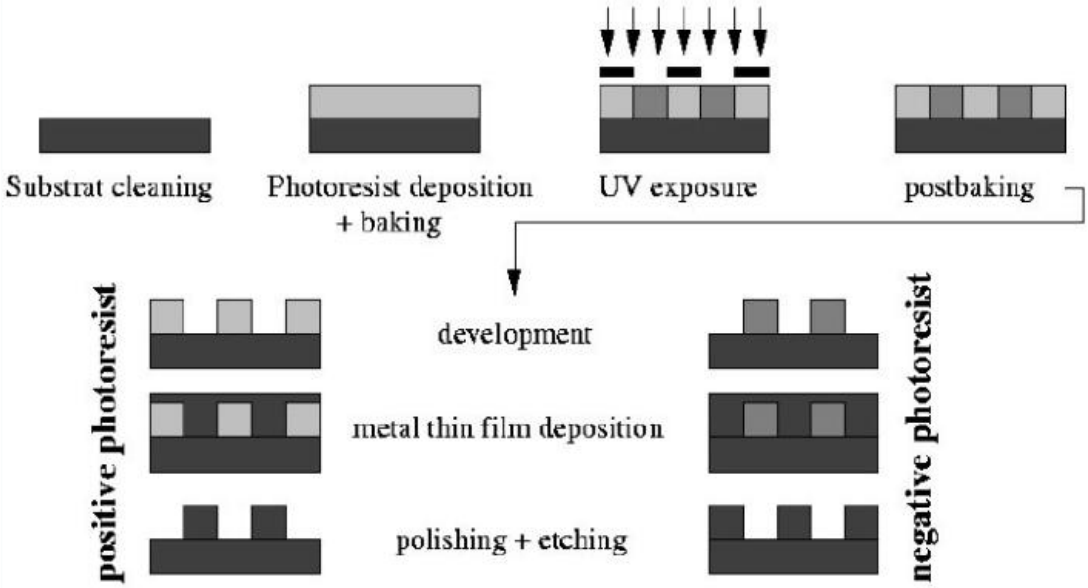
2. **Magnetic responsiveness**: Exhibits strong magnetic properties for smart and controllable device applications.

3. **Improved thermal stability**: Nanoparticles enhance heat resistance and increase thermal conductivity.

4. **Enhanced electrical properties**: Fe_3O_4 provides tunable electrical conductivity for EMI shielding and sensing.

5. **Good chemical resistance**: Stable against solvents, moisture, and corrosion environments.

Applications in sensors:



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