23MPP561

Nanomaterials and Composites

Semester 1 2023/24 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer **ALL THREE** questions. Each question carries 20 marks.

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1. (a) Describe TWO reasons why surface/facet tailoring of nanosized photocatalysts could lead to improved photocatalytic efficiency. [4 marks]

(b) An engineer has been asked to produce a nanostructured photoactive metal oxide thin film coated on a transparent conducting oxide substrate. For each of the following properties, provide one method that could be used to characterise the:

(i) thin film's thickness; [1 mark]

(ii) thin film's bandgap; [1 mark]

(iii) average crystallite size of the coated film; [1 mark]

(iv) oxidation state of the metal ions in the film. [1 mark]

(c) An oxide ceramic has been investigated for its potential use as a photoanode in solar water splitting, and the following challenges have been identified as main barriers in further commercial exploitation. State FOUR viable solutions to overcome the following challenges:

(i) The large overpotential at the photoanode and slow kinetics of oxygen evolution; [3 marks]

(ii) The short diffusion length of charge carriers. [1 mark]

(d) Silicon negative electrodes (anodes) in Li-ion batteries can surpass the theoretical capacities of commercial graphite anodes by approximately 10-fold, however, practical applications of Si anodes are very limited. Describe the main challenge in commercial application of Si anodes and provide two solutions that can overcome this. [4 marks]

(e) SiC whisker-reinforced aluminas are effective composites as cutting tool inserts for machining hard metals. State FOUR possible toughening mechanisms responsible for increasing the performance of these composites. [4 marks]

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2. (a) An engineer has been asked to evaluate three carbon nanotube (CNT) supercapacitor electrodes, A, B and C, given in Table Q2. The three electrodes have been coated on to 10×10 cm metallic substrates using three different coating techniques. Rank the three manufacturing methods based on their suitability to produce supercapacitors with highest volumetric capacitance and provide a justification for your answer. [6 marks]

Table Q2. Properties of three supercapacitor electrodes under consideration

Electrode	CNT Density in g cm^{-3}	Electrode Specific Surface Area in m^2 g^{-1}	Electrode Thickness in μm	Electrode Manufacturing Method
A	2.11	40	25	Tape Casting
B	2.11	85	10	Spray Coating
C	2.11	25	25	Electrodeposition

(b) Explain why ceramic matrix nanocomposites are generally more difficult to fabricate as compared to monolithic ceramics. [4 marks]

(c) Using the synthesis of nano iron oxide/silicon oxide particles with core-shell structures via water in oil microemulsion as an example:

(i) Give the definition of a water in oil (W/O) microemulsion; [2 marks]

(ii) Provide an experimental flow chart for the synthesis; [2 marks]

(iii) Discuss the advantages of the microemulsion approach and the iron oxide/silicon oxide composite nanoparticles synthesised for medical applications. [6 marks]

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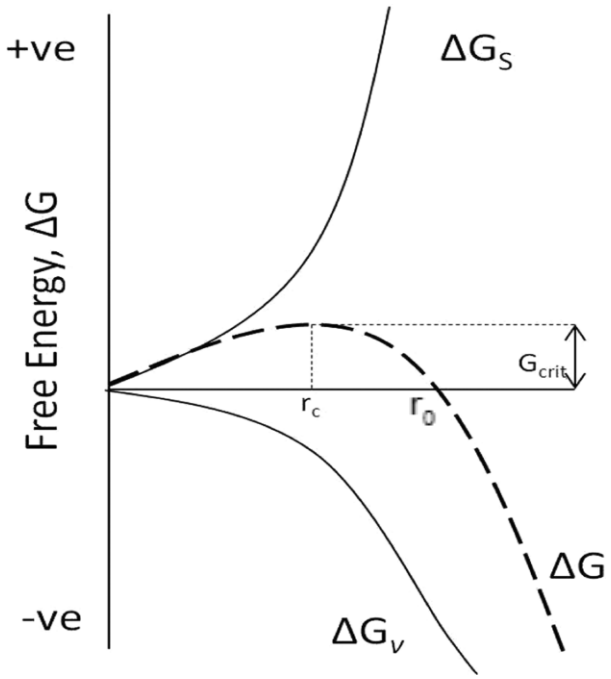
3. Nucleation and crystal growth are the two key steps in synthesis of nano-crystals via wet chemistry routes, including co-precipitation, hydrothermal and sol-gel processes below:



$$\Delta G = \frac{4}{3}\pi r^3 \Delta G_v + 4\pi r^2 \gamma$$

Figure Q3. Schematic of changes of free energy as a function of nucleus radius

(a) Define and interpret r_c, r_0 and $G_{crit.}$, using classical nucleation theory and a schematic diagram (Figure Q3). [3 marks]

(b) Describe the mechanism of formation of nano-crystals in solution. [4 marks]

(c) Discuss how to control the size and morphology of nano-crystals synthesised through control of reaction parameters and additives. [8 marks]

(d) Compare the advantages and disadvantages in the preparation of ceramic nanoparticles using the co-precipitation or hydrothermal methods. [5 marks]

END OF PAPER

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