Loughborough University

24MPP561
Nanomaterials and Composites

Semester 1 2024/25 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 **THREE** questions.

1. (a) Morphology and nanostructure control has been employed as an effective strategy to improve the performance of oxide electrodes for photoelectrochemical devices. For the case of a thin film hematite photo-electrode in a solar driven hydrogen generation device,

   (i) discuss the inherent limitations in light harvesting efficiency and charge carrier transport in a planar hematite photo-anode; and, [4 marks]

   (ii) describe the characteristics of the ideal morphology for a nanostructured hematite photo-anode in this application. [6 marks]

   (b) Explain why surface/facet tailoring of nanosized photocatalysts could lead to improved photocatalytic efficiency. [6 marks]

   (c) Considering the Hall-Petch effect, discuss the effect of reduction in grain size on the hardness of nanocrystalline materials. [4 marks]

2. (a) An engineer has been asked to produce a porous supercapacitor electrode made from graphene-based nanomaterials. For each of the following parameters, provide one method that could be used to characterise:

(i) electrode's thickness; [1 mark]

(ii) electrode's pore size distribution; and, [1 mark]

(iii) C:O ratio on the carbon surface. [1 mark]

(b) A research project is planned to study the kinetics of nanocrystal nucleation and growth. State how you would use the following techniques to inform your research. In your answer you should comment on the suitability of each method to investigate relevant parameters, including particle size, crystallinity, and growth rate. State any inherent limitations with the proposed techniques.

(i) *in situ* Transmission Electron Microscopy (TEM) [3 marks]

(ii) *in situ* X-ray Absorption Fine Structure (XAFS) [3 marks]

(iii) *in situ* Wide Angle X-ray Scattering (WAXS) [3 marks]

(c) Explain the significance of pore size distribution in activated carbon for supercapacitor applications. [4 marks]

(d) Describe the concept of a miscibility gap in $LiFePO_4$ as positive electrodes in Li-ion batteries and explain how it changes with particle size. [4 marks]

3. (a) Explain why ceramic matrix nanocomposites are generally more difficult to fabricate as compared to monolithic ceramics. [5 marks]

(b) Briefly describe how composite coatings enhance the tribological properties of a component when the coating is harder than the substrate. State two common processing techniques to manufacture such coatings. [4 marks]

(c) Nucleation and crystal growth are the two key steps in synthesis of nanocrystals via wet chemistry routes such as co-precipitation and sol-gel processes. Using the classical nucleation theory and the schematic diagram provided in Figure Q3c,

(i) define and interpret r_c, r_0 and G_{crit}; [3 marks]

(ii) describe the mechanism by which nanocrystals are formed from solutions; and, [4 marks]

(iii) explain how the level of supersaturation impacts particle size and distribution of nanocrystals. [4 marks]

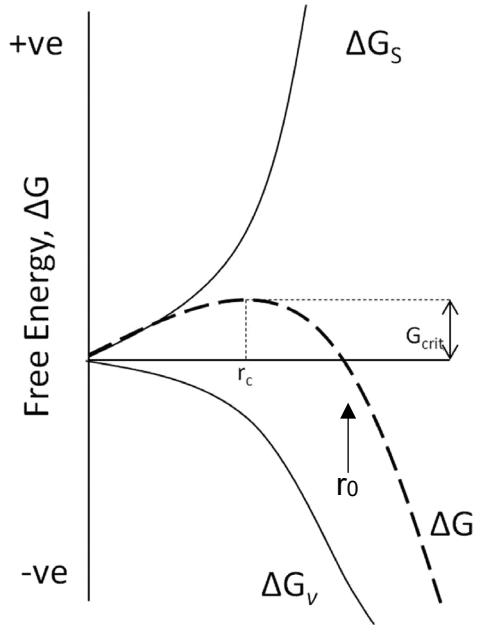

Figure Q3c

END OF PAPER

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