SEMESTER 2 EXAMINATIONS 2012-2013

NANOSCIENCE: TECHNOLOGY AND ADVANCED MATERIALS

DURATION 120 MINS (2 Hours)

This paper contains 8 questions

Answer **ALL** questions in **Section A** and **only TWO** questions in **Section B.**

Section A carries 1/3 of the total marks for the exam paper and you should aim to spend about 40 minutes on it.

Section B carries 2/3 of the total marks for the exam paper and you should aim to spend about 80 minutes on it.

An outline marking scheme is shown in brackets to the right of each question.

A Sheet of Physical Constants is provided with this examination paper.

Only University approved calculators may be used.

A foreign language translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

Page 1 of 5 + Appendices (Sheet of Physical Constants)

Section A

A1. Provide four examples of commercially available nanotechnology products. [4 marks]

A2. Draw a diagram of a carbon nanotube field effect transistor, labelling all the important components and show how the conductance varies as a function of gate voltage for such a device. Provide an explanation for the observed conductance vs. voltage characteristics. [4 marks]

A3. State whether Scanning Probe Microscopies are operated in the far-field or near-field regime and provide an explanation for your answer. [4 marks]

A4. Explain why nanoparticles have different properties to the bulk. Give two examples of properties that change at the nanoscale and explain them. [4 marks]

A5. What are the advantages of using quantum dots as fluorescent dyes instead of the typical organic dyes? State and explain six different reasons. [4 marks]

SECTION B

B1.

(a) Discuss the differences in the absorption spectra (in terms of number of peaks, intensity of the plasmon band and wavelength of the maximum absorption) of:

(i) a silver sphere of 40 nm diameter, and a silver cube with sides of length 40 nm.

(ii) a silver octahedron with dimensions of 40 nm and a silver triangular plate of 40 nm maximum width and 5 nm height.

(iii) a silver disk and a silver sphere both of 40 nm diameter.

(iii) a 40 nm silver octahedron and a silver cube of side 40 nm.

[8 marks]

(b) Explain how the optical properties of quantum dots differ from the optical properties of metal nanoparticles. Draw a graph of the density of states in each case.

[7 marks]

(c) Briefly describe the basic operating principle of Scanning Tunnelling Microscopy (STM) and how it can be used to obtain geometrical information.

[5 marks]

Section B continues on the next page

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B2.

(a) Scanning Tunnelling Microscopy (STM) can be used for atomic manipulation. Suppose that you have constructed a linear chain with length L of atoms using metallic atoms on a surface:

(i) Assume that the valence electrons in this system can be approximated by a nearly free-electron model with an effective electron mass of 0.9 m_e*.
Calculate the energy difference between the ground state and the first excited state of the valence electrons. You may assume that no electron leakage occurs at both ends and sides of the chain.

(ii) What is the minimum length of the chain if you want to observe the energy gap calculated in (i) experimentally, at liquid nitrogen temperatures?

[12 marks]

(b) (i) What is self-assembly? What are the principles of molecular self-assembly? Name two self-assembly interactions that are taking place between two DNA strands. [4 marks]

(ii) What does SAMs stand for? Discuss one example of SAMs and name three applications. Name four ways that the self-assembly of block co-polymers can be directed. Name four applications. [4 marks]

Section B continues on the next page

B3.

(a) (i) Draw a sketch of monomer concentration versus time during the nucleation and growth of a nanoparticle. Discuss the nucleation and growth process.

[6 marks]

(ii) Assume a spherical nanoparticle nucleus with a radius of r. The total change of the Gibbs' free energy for the formation of the nucleus (ΔG_{nuc}) is given by:

$$\Delta G_{nuc} = \Delta G_v \frac{4}{3}\pi r_{nuc}^3 + \gamma 4\pi r_{nuc}^2$$

ΔG_{nuc} = change of Gibbs free energy
ΔG_v = change of volume free energy
γ= surface energy per unit area

The nucleus will be stable only when its radius exceeds a critical size, r^*. Show that critical size, r^*, and critical energy (ΔG^*) are given by:

$$r^* = -\frac{2\gamma}{\Delta G_v} \quad , \quad \Delta G^* = \frac{16\pi\gamma^3}{3\Delta G_v^2}$$

[6 marks]

(b) (i) Describe what happens during photolithography and discuss its main advantages and disadvantages. Describe an alternative to photolithography, which overcomes these disadvantages. [6 marks]

(ii) Assuming that visible light is used, estimate the size of the smallest feature that could be produced on silicon by photolithography. [2 marks]

END OF PAPER