SEMESTER 2 EXAMINATION 2014-2015

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 mins on it.

Section B carries 2/3 of the total marks for the exam paper and you should aim to spend about 80 mins 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 word to word® translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

Section A

A1. Conventional photolithography is reaching its limit in the fabrication of integrated circuits. Explain what this limit is and why it exists and name two other "top-down" nanofabrication methods. [4]

A2. Define the tunneling current (I_t) that can be measured in scanning tunneling microscopy, stating all the terms in this definition. Why is the spatial resolution of the STM better than the AFM? [4]

A3. (i) Give two reasons to justify that surface-enhanced Raman scattering is an intrinsically nanoscale phenomena.

(ii) What is surface plasmon resonance? What will happen to the surface plasmon resonance peak with increasing size in spherical gold or silver nanoparticles?

[4]

A4. Explain the electrostatic and steric surface stabilisation of colloidal inorganic nanoparticles. Name and explain the two types of interactions between the ligand and the surface of the nanoparticle. What are the advantages of steric stabilisation against electrostatic stabilisation ? (Assume that sterically stabilised particles are fully covered with ligands). [4]

A5. What is the bottom-up synthetic approach? What drives this approach? Name three synthetic methods where the bottom-up approach is employed. [4]

Section B

B1. (a) Describe the Coulomb blockade effect and Coulomb staircase in a single electron transistor with the aid of a diagram that shows the charge vs. voltage behaviour. [10]

(b) Consider the conducting islands isolated in a single electron transistor. For the transistor to work at room temperature, what should the capacitance of the island be? If the island can be modelled as a sphere, calculate its radius. [6]

(c) Sketch and explain the difference between charging up a capacitor via classical polarization and via a quantum tunnelling process. [4]

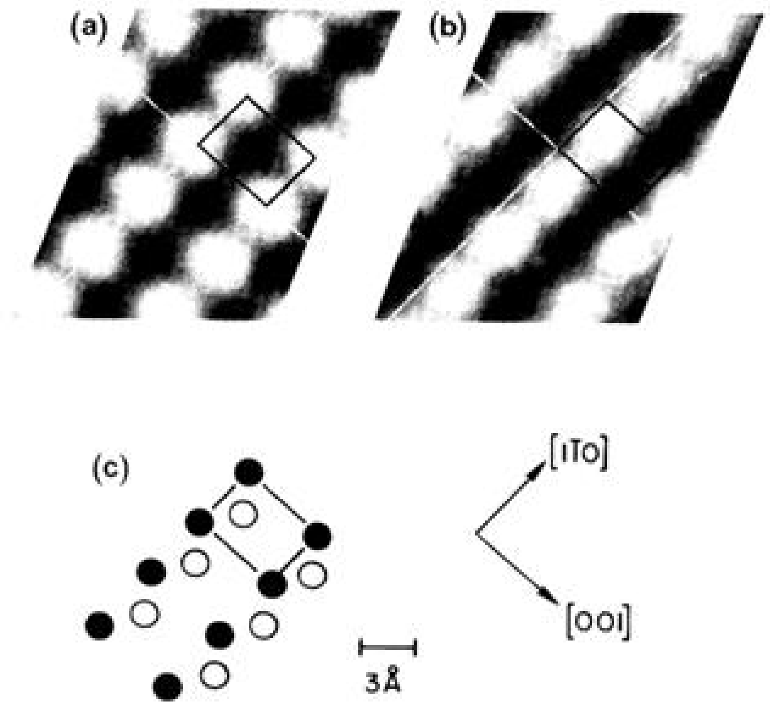
TURN OVER

B2. (a) Scanning probe microscopies are invaluable tools for the nanoscale characterization of surfaces and structures.

(i) State whether for semiconductor surfaces the STM images acquired depend on the polarity of the bias voltage and justify your answer. [4]

(ii) In the simplest limit an STM image represents contours of constant tunneling current. Under what conditions does this simple limit break down? Name two reasons. [2]

(ii) The following constant-current STM images were acquired on the GaAs (110) surface at a bias voltage of +1.9 V (left-hand image) and -1.9 V (right-hand image). What can be observed in the images at different bias voltages and why? [2]



(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. [6]

(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:

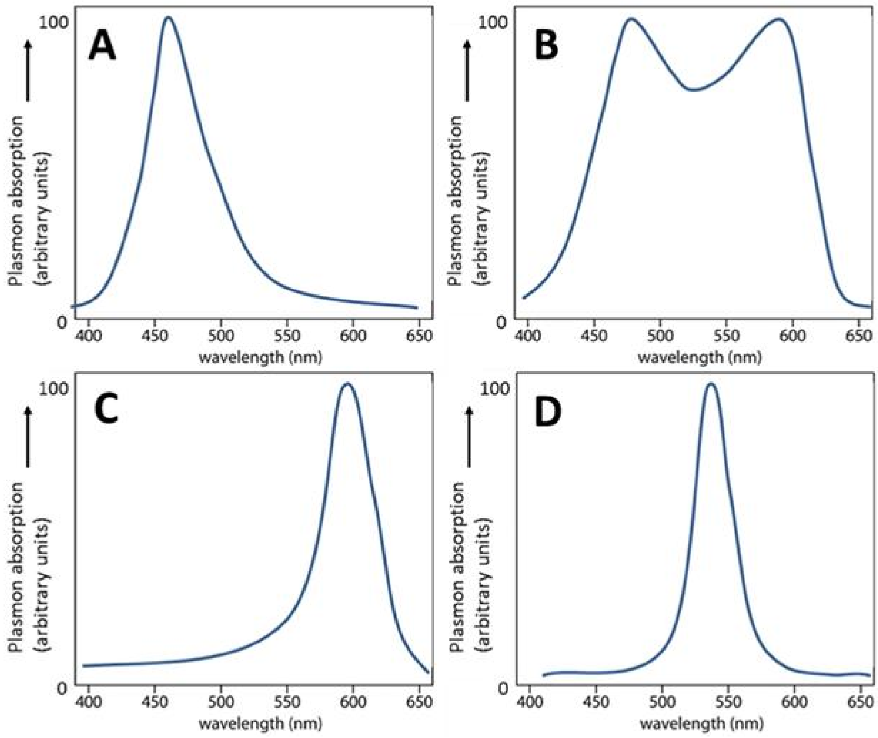
$$r^{*} = -\frac{2\gamma}{\Delta G_{v}}, \qquad \Delta G^{*} = \frac{16\pi\gamma^{3}}{3\Delta G_{v}^{2}}$$

[6]

TURN OVER

B3. (a) (i) Sketch schematically the plasmon mediated surface-enhanced Raman spectroscopy (SERS) process and clearly indicate on the diagram or list below it the five steps involved. [8]

(ii) Plasmon absorption spectra for four nanoscale metallic structures A, B, C and D are shown in the figure below. If an excitation laser at 488 nm is used and the Raman scatter is observed at 600 nm for doing SERS experiments, which one of these is likely to show the highest SERS signal and which the lowest? Also give a reason for each of your two choices. [4]



(b) (i) In the following equation of motion for electrons used in the Drude model, m is the electronic mass, r is their displacement, e is electronic charge and E is the electric field; what is Γ? Will its value be higher or lower for a highly conducting metal compared to a non-conducting metal? Justify your answer.

$$m\frac{\partial^2 r}{\partial t^2} + m\Gamma\frac{\partial r}{\partial t} = -eE$$

[2]

(ii) Using the above equation and the expressions for periodic E and r ($E = E_0 e^{-it}$ and $r = re^{-it}$) derive an expression for r in terms of m, E, e and Γ. [2]

(iii) Using the above derived expression for r, and given that polarization (P) in a material can be written both in terms of displacement (r) of electrons as well as material susceptibility (χ) that is, $P = -Ner = \epsilon_0 \chi E$, where N is number of electrons, derive the expression for the dielectric function ($\epsilon_\omega = 1 + \chi$) of the material. Use this expression to define the bulk plasmon frequency (ω_p) in terms of N, e, m and ϵ_0. [4]

END OF PAPER