ENGINEERING TRIPOS PART IIB

Thursday 12 May 2011 2.30 to 4

Module 4B5

NANOTECHNOLOGY

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** number of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering data book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the invigilator

(TURN OVER

1 (a) Define the term "*Nanotechnology*". Explain, using examples of the following topics why an understanding of basic quantum mechanics is essential in the field of nanotechnology:

(i) tunneling;

(ii) hot-electron and resonant tunnelling devices.

[40%]

(b) Fig. 1(a)-(e) below is a sequence of simulations of a wave packet incident upon a narrow rectangular potential barrier, where the mean packet energy, E is slightly lower than the barrier height, V. By reference to the figures, that show the modulus squared of the wave-function as a function of position after successive time intervals, explain how the wave packet evolves before, during and after interaction with the barrier, and discuss how this would change for the case of a plane wave incident upon the barrier. [60%]

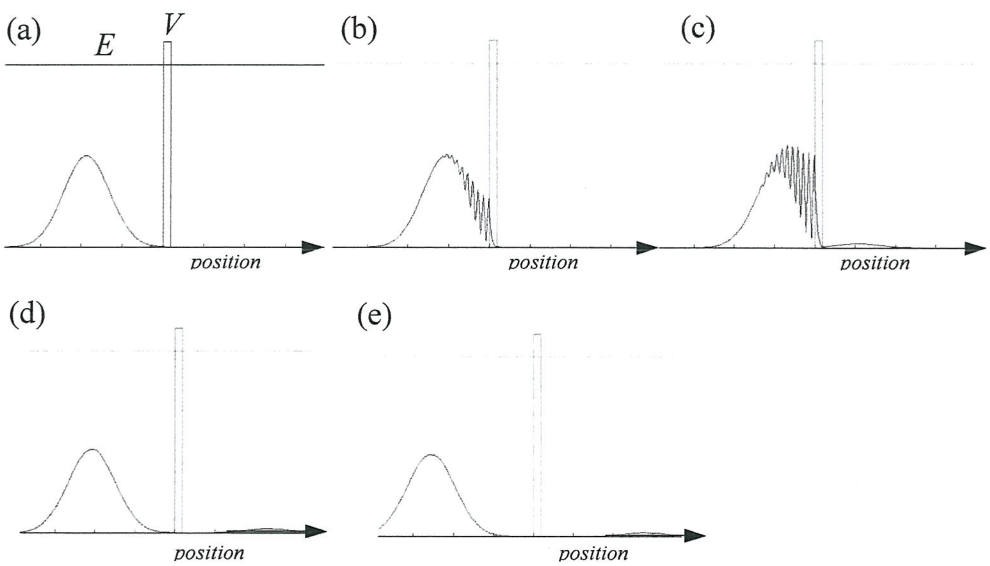

Fig. 1

2 (a) Describe, with the aid of diagrams, the double-slit electron interference experiment, with particular reference to the key results and their interpretation. How is this relevant to electrical engineering? [30%]

(b) With reference to their de Broglie wavelengths, which of the following systems can be meaningfully described using quantum mechanics, and why:

(i) a dust particle of mass 10^{-14} g, which is travelling at a velocity of 10 nm s^{-1}

(ii) a hydrogen molecule moving at 10 m s^{-1}

[30%]

(c) Fig. 2 illustrates a beam of electrons of energy 1.5 eV incident on a potential step of height 1 eV. Determine the probability that the electrons have of being transmitted past the potential step, given that the effective mass of the electrons is reduced by 50% once they pass the step. How would you expect the transmission probability to change if we were to consider a single electron rather than a beam? [40%]

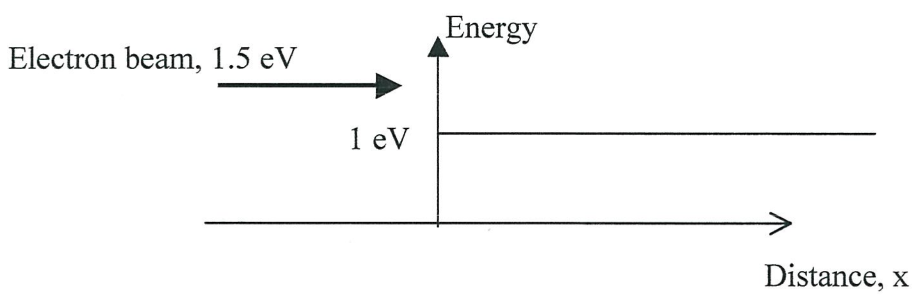

Fig. 2

3 (a) Describe the basic principle of field emission, using an energy diagram to illustrate your answer. [20%]

(b) Briefly discuss the concepts behind the WKB (Wentzel-Kramers-Brillouin) approximation, and show the steps required to derive the transmission probability, T, of an arbitrary tunnelling barrier, stating any assumptions made. [30%]

(c) Consider the case of a positive voltage applied to the surface of a metal, and using the WKB approximation, calculate an expression for the probability for electrons to be extracted from the surface as a function of the applied voltage. What is the relationship between this probability and the field emission current? Comment on the accuracy of the WKB approximation for this problem. [40%]

(d) What is a practical application of field emission? [10%]

4

(a) Sketch the no-bias band diagram for a resonant tunnelling diode formed by highly doping a *p-n* junction. [15%]

(b) Sketch the typical current vs voltage characteristic for the device, labelling the key features. For each section of the characteristic, draw the corresponding band diagram. [55%]

(c) How are these devices made? Briefly discuss how such a device may be used in a real-life application. [30%]

5 (a) State Moore's law. Discuss briefly the advances in technology that have enabled the continued increase in the speed of operation of transistors, with particular emphasis on device architectures and the choice of materials. Discuss the driving force behind the continued miniaturisation of transistors. [30%]

(b) Discuss the fundamental, physics-imposed limitations to the continued miniaturisation of field-effect transistors. [40%]

(c) Describe the basic principles of fabrication and operation of molecular electronic devices, with emphasis on size, speed and reproducibility. [30%]

END OF PAPER