Royal Holloway

UNIVERSITY OF LONDON

MSci EXAMINATION

NANOTECHNOLOGY CP4505A

SUMMER 1999

Time Allowed: TWO HOURS

Answer **TWO** questions only. No credit will be given for attempting a further question.

Each question carries 20 marks. The mark *provisionally allocated* to each section is indicated in the margin.

TURN OVER WHEN INSTRUCTED

GENERAL PHYSICAL CONSTANTS

Permeability of vacuum	m_0	=	$4\pi \times 10^{-7}$	$\mathrm{H\ m^{-1}}$
Permittivity of vacuum	e_0	=	8.85×10^{-12}	$\mathrm{F\ m^{-1}}$
	$1/4\pi e_0$	=	9.0×10^{9}	$\mathrm{m\ F^{-1}}$
Speed of light in vacuum	c	=	3.00×10^{8}	$\mathrm{m\ s^{-1}}$
Elementary charge	e	=	1.60×10^{-19}	C
Electron (rest) mass	m_e	=	9.11×10^{-31}	kg
Unified atomic mass constant	m_u	=	1.66×10^{-27}	kg
Proton rest mass	m_p	=	1.67×10^{-27}	kg
Neutron rest mass	m_n	=	1.67×10^{-27}	kg
Ratio of electronic charge to mass	e/m_e	=	1.76×10^{11}	$\mathrm{C\ kg^{-1}}$
Planck constant	h	=	6.63×10^{-34}	J s
	$h = h/2\pi$	=	1.05×10^{-34}	J s
Boltzmann constant	k	=	1.38×10^{-23}	$\mathrm{J\ K^{-1}}$
Stefan-Boltzmann constant	s	=	5.67×10^{-8}	$\mathrm{W\ m^{-2}\ K^{-4}}$
Gas constant	R	=	8.31	$\mathrm{J\ mol^{-1}\ K^{-1}}$
Avogadro constant	N_A	=	6.02×10^{23}	$\mathrm{mol^{-1}}$
Gravitational constant	G	=	6.67×10^{-11}	$\mathrm{N\ m^{2}\ kg^{-2}}$
Acceleration due to gravity	g	=	9.81	$\mathrm{m\ s^{-2}}$
Volume of one mole of an ideal gas at STP		=	2.24×10^{-2}	$\mathrm{m^{3}}$
One standard atmosphere	P_0	=	1.01×10^{5}	$\mathrm{N\ m^{-2}}$

MATHEMATICAL CONSTANTS

$e = 2.718$ $\pi = 3.142$ $\log_e 10 = 2.303$

PART MARKS

1. (a) What are meant by the terms *phase-breaking length* L_ϕ and *weak localisation* in a conductor?

    Over what temperature range does the conductor with the parameters given below behave as (a) a one-dimensional (1D) conductor and (b) as a 2D conductor with respect to the weak localisation effect?

    The conductor is a rectangular strip with dimensions: L_x =10 μm in the direction of the current, L_y =200 nm and L_z = 10 nm in the transverse directions. The elastic scattering rate for the conduction electrons, $\tau^{-1} = 10^{13}$ s^{-1}; the phase breaking rate has a temperature dependence $\tau_\phi^{-1} = AT^3 \mathrm{s}^{-1}$ with $A = 10^8$ s^{-1}K^{-3}; the Fermi velocity, $v_F = 10^6$ m/s. **[7]**

    (b) Calculate the temperature dependence of the weak localisation correction to the resistance in the 1D and 2D cases for the same conductor. **[8]**

    (c) Describe qualitatively the changes in the resistance of the conductor with magnetic field. What is the difference in the behaviour of the conductor in an applied magnetic field H, parallel to the x, y, and z axes? Analyze both the 1D and 2D cases. **[5]**

2. (a) Describe the negative process for the e-beam fabrication of metallic nanostructures. **[3]**

    (b) Give three examples of nanotechnology techniques based on the use of a scanning probe. **[3]**

    (c) Describe the "self-alignment" nanofabrication technique. Give an example used for the fabrication of sub-micron tunnel junctions. **[4]**

    (d) How does the resolution of a positive e-beam resist depend on the contrast? Use a two-Gaussian model for the proximity effect and an isotropic local model for the development process **[7]**

    (e) Explain the physical limitations of the resolution of photo-lithography and X-ray lithography. How the resolution depend on the contrast of the resist in each case? **[3]**

PART MARKS

3. (a) What is a mesoscopic conductor? Show that in a mesoscopic conductor the probability W, for an electron to get from point a to b differs from the classical value. **[3]**

(b) Show that, in a mesoscopic conductor, quantum interference leads to quantum fluctuations in the probability W. **[5]**

(c) Explain the meaning of the Universal Conductance Fluctuations (UCF) in diffusive mesoscopic conductors by using dimensional analysis of the expression for the conductance. **[5]**

(d) Show that changes in the resistance of a mesoscopic metallic conductor take place in classically weak magnetic fields H, $\omega_c\tau \ll 1$, where $\omega_c = \frac{eB}{m}$, is the cyclotron frequency and τ is the mean time between collisions. **[7]**

Magnetic flux quantum $\phi_0 = \frac{h}{2e}$.

END