Version FT/2

EGT3
ENGINEERING TRIPOS PART IIB

Thursday 26 April 2018 14.00 to 15.40

Module 4B22

FLEXIBLE ELECTRONICS

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

All questions carry the same number of marks.

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

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS

Single-sided script paper

Graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM

CUED approved calculator allowed

Engineering Data Book

Attachment: 4B22 Flexible Electronics data sheet (1 page)

10 minutes reading time is allowed for this paper at the start of the exam.

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

1 (a) List the advantages and drawbacks of silver nanowire-, CVD graphene- and solution processed graphene-based transparent conductors in terms of percolation, deposition, stretchability, adhesion, electromigration and haze. Briefly explain with a schematic how silver nanowires could be used to fabricate a stretchable transparent conductor. [25%]

(b) Describe the stretchable wavy ribbons strategy to obtain stretchable electronic gold interconnects. Considering a gold wavy ribbon interconnect, what is the effect of the ribbon's width on the wavelength and the amplitude of the ribbon's waves? [20%]

(c) List two semiconducting materials for flexible electronics that can be processed at low temperature and discuss their respective advantages and disadvantages. Why is low temperature processing preferred in flexible electronics? [25%]

(d) Fig. 1 shows a graphical model of BioImpedance Vector Analysis (BIVA), where R/Ht and Xc/Ht represent the values of resistance and reactance of a human body, normalized by the body height (Ht):

(i) briefly explain what the ellipses marked at 50%, 75% and 95% represent,

(ii) explain the meaning of the 4 axes directions (A, B, C, D) in terms of body fluids and body lean mass increase or decrease,

(iii) describe a non-invasive method to measure the body impedance by a wearable device and derive a building block electrical schematic of a suitable system for bioimpedance measurement. [30%]

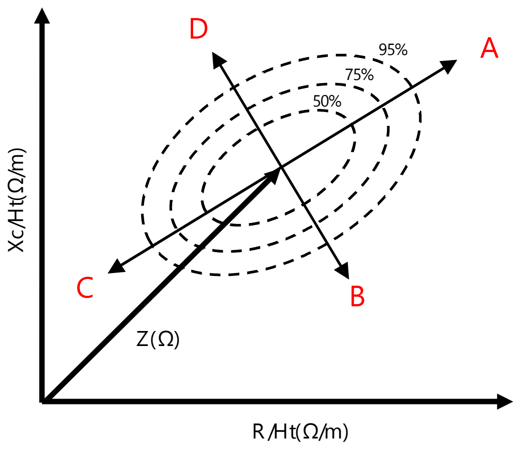

Fig. 1

2 (a) Discuss the key assumptions made in the free-electron model. What is the form of the electronic wave-function in this model? Why is the electron energy plotted against the k-space instead of the real space? What are the limitations of the free-electron model? [25%]

(b) Derive the expression for the current, I_D in a coplanar Thin Film Transistor (TFT) operating in the linear region. Assume a mobility of induced carriers μ_d, a channel width W, and a channel length L. What is the condition required to form a conductive channel between source and drain? What is the condition required to achieve saturation of I_D? [25%]

(c) Sketch and compare a TFT architecture with a Metal Oxide Semiconductor Field Effect Transistor (MOSFET), highlighting the key differences in terms of the charge transport and the enabling factors for flexible electronics. [25%]

(d) An ink manufacturer needs to formulate a nanoparticle-based ink for the deposition of a series of electrodes of dry thickness d = 25 μm by screen printing. Considering that the volume of the screen is V_{screen} = 0.1 m^3 and the pick-up ratio is K_p = 0.6, what would be the targeted viscosity (η) of the ink, if the maximum density is ρ_{max} = 600 g l^{-1}. [25%]

3 (a) Explain the relationship between the carrier mobility μ and the temperature T in conducting polymers at high temperatures. How does the thermal energy affect the electron transfer process in conducting polymers? [25%]

(b) *Trans*-polyacetylene has a band size of E_0 = 6.4 eV. The value of the electron energy E relative to the Fermi energy E_F is E-E_F ~ 1.2 eV and E is defined by ka = $14\pi/30$, where k is the momentum and a is the lattice spacing. What is the band-gap? What is the value of ka for an energy of $2E$? [30%]

(c) List and sketch the two staggered TFT configurations. With the help of a sketch, describe the contribution of the access resistance $R_{S/D}$ in the total resistance R_T of a staggered TFT device. Estimate $R_{S/D}$ using the plot of R_T measured as a function of the channel length L for the various gate voltages V_g shown in Fig. 2. [20%]

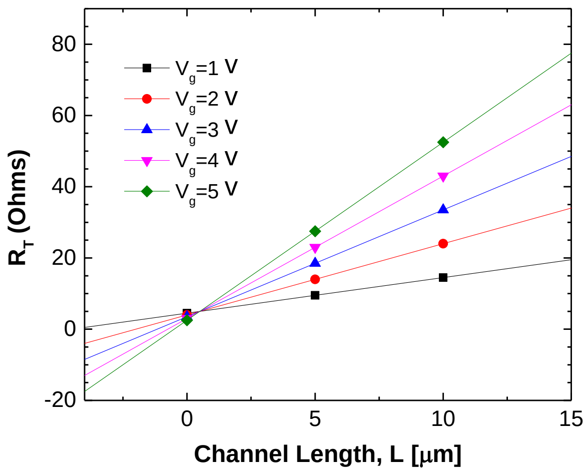

Fig. 2

(d) Define the general equation describing the Variable Range Hopping (VRH) of charge carriers through a conductor in 3-dimensions (3D). What is the difference with the 1-dimensional (1D) VRH case? What is the mechanism limiting the hopping in the 1D and the 3D cases? [25%]

4 (a) Sketch and explain the strain distribution across the perpendicular section of a uniaxially bent film. [20%]

(b) A large-area thin film is deposited on a flexible substrate. How can the concept of neutral plane be used to reduce the strain on the thin film, under uniaxial bending? State any assumptions made. [25%]

(c) Define the free carrier plasma resonance frequency for a conducting material. If the free-carrier density is $n = 3.21 \times 10^{21}$ cm^{-3}, what will be the upper cut-off wavelength of this material when it is exposed to electromagnetic radiation? Would the conducting material be suitable as a transparent conducting film for a standard full-colour display application? [25%]

(d) A water-based ink contains 20 wt% of monodispersed silver nanowires with an average length L = 6 μm and an average diameter D = 50 nm. Assume the nanowires have ideal cylindrical shapes, water density is 1 g cm^{-3} and silver density is 10 g cm^{-3}. What is the minimum volume of dispersion required to cover an area of 10 cm × 10 cm to achieve uniform percolation? [30%]

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Module 4B22 – Flexible Electronics

Data sheet

Einstein-Batchelor equation

$$\eta = 1 + 2.5\phi + 6.2\phi^2$$

Where ϕ is the mass fraction.

Power level at a distance *x* in a p-i-n photodiode

$$P_{eff}(x) = (1 - R)P_{in}e^{-\alpha_s x}$$

Where R is the reflectance, P_{in} is the input power and α_s is the absorption coefficient.

Energy of a travelling electron (Su-Schrieffer-Heeger model)

$$E(\mathbf{k}) = \epsilon_F + \sqrt{E_0^2 cos^2(ka) + (E_g^2/2)\, sin^2(ka)}$$

Where E_g is the bandgap, $2E_0$ is the band width and ϵ_F is the energy at the centre of the band gap.

Hopping conductivity

$$\sigma(T) = \sigma_0 \exp -(T_0/T)^{\frac{1}{d+1}}$$

Where T is the temperature, T_0 is the critical temperature, d is the dimensionality of the system.

Child's law

$$j = \frac{9\varepsilon_r\varepsilon_0\mu V^2}{8s^3}$$

Where ε_0 and ε_r are the vacuum and the relative permittivity, V is the voltage, s is the distance between the capacitor's parallel plates and μ is the charge mobility.

4B22 NUMERICAL Answers

Q2

c)

$\eta = 1 + 2.5\,\phi + 6.2\,\phi^2 = 2$

Q3

b)

Eg = 1.5 eV, Ka~ 1.323 rad.

Q4

c)

Lambda=589.64 nm

d)

Min volume = 7.66 ul