Version FT/3

EGT3
ENGINEERING TRIPOS PART IIB

Monday 29 April 2019 14.00 to 15.40

Module 4B22

FLEXIBLE AND STRETCHABLE 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 four layers composing a flexible electronic system. What is the role of the back-plane and front-plane in enabling flexible electronic displays? [20%]

(b) Describe the non-coplanar mesh strategies to obtain stretchable electronic gold interconnects. Considering straight interconnects, what is the effect of the ribbon's length on the wavelength of the ribbon's waves? [25%]

(c) List two conducting 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) Figures 1(a) and 1(b) show two different configurations of a unipolar inverter fabricated using *p*-type Thin Film Transistors acting as "drive" and "load" respectively.

(i) Explain the key aspects of the two configurations and discuss at least one advantage and one disadvantage for each configuration. [15%]

(ii) Discuss the presence of overlap capacitance and contact resistance in these circuits, and describe their role on the switching speed of the inverters. [15%]

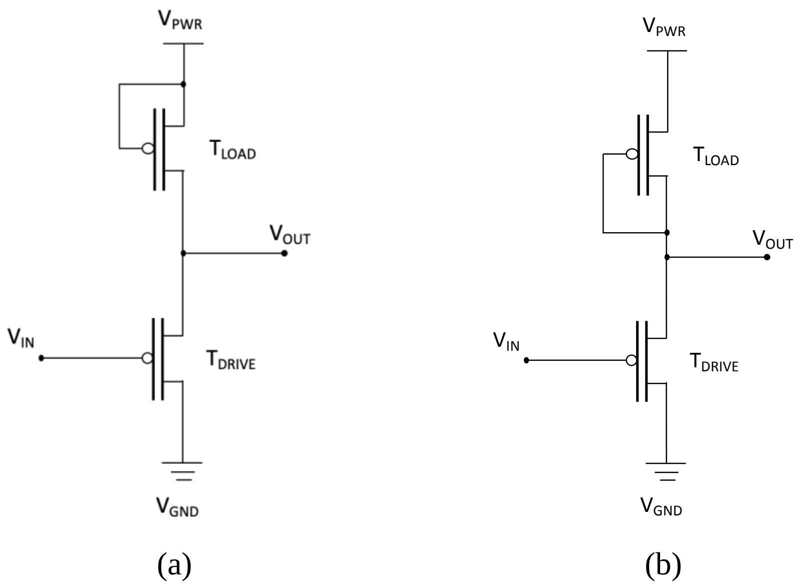

Figure 1

2 (a) Discuss the key assumptions made in the free-electron model. What are the limitations of the free-electron model? State Bloch's theorem and discuss its implementation in the nearly free-electron model. [25%]

(b) A potential difference of V_d = 5 V is applied across a semiconducting polymer layer of thickness d = 125 nm and dielectric constant ε_r = 5.1. The transport properties of the polymer with two different doping levels are: in the first case a charge density n_1 = 0.7 x 10^{19} m^{-3}, a trap density n_{trap1} = 4.5 x 10^{10} m^{-3} and a mobility μ_1 = 4.2 x 10^{-8} m^2 V^{-1} s^{-1}. In the second case a charge density n_2 = 4.6 x 10^{21} m^{-3}, a trap density n_{trap2} = 7.4 x 10^{18} m^{-3} and a mobility μ_2 = 8.7 x 10^{-11} m^2 V^{-1} s^{-1}. Calculate the corresponding current fluxes, j_1 and j_2, for the first and second case, using Child's law. [25%]

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

(d) Briefly discuss how the dimensionality of nanomaterials affects the macroscopic electrical properties of flexible electrodes. An ink manufacturer needs to formulate a nanoparticle-based ink for the deposition of a series of electrodes of dry thickness d = 50 μm by screen printing. Considering that the volume of the screen is V_{screen} = 0.2 m^3 and the pick-up ratio is K_p = 0.3, what would be the targeted viscosity (η) of the ink, if the maximum density is ρ_{max} = 300 g l^{-1}. [25%]

3 (a) Explain the relation between carrier mobility μ and temperature T in conducting polymers at high temperatures. How does the thermal energy affect the electron transfer process in conducting polymers? [30%]

(b) Discuss the key assumptions made when deriving the electronic band model of a generic three-dimensional semiconductor. Explain what the *k*-space is. Why is the electron energy plotted against the *k*-space instead of the real space? [25%]

(c) Identify each of the components and materials marked as A, B, C, D, E, F in the Indium Gallium Zinc Oxide (IGZO) TFT shown in Figure 2. Describe a suitable deposition technique for the IGZO layer on a flexible substrate and explain why this is the preferred option. [25%]

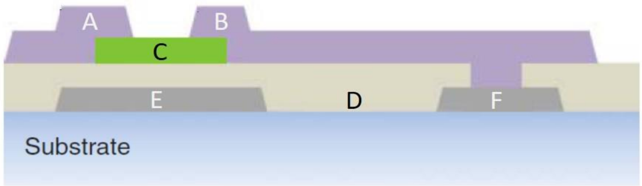

Figure 2

(d) Define the general equation describing 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? [20%]

4 (a) 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%]

(b) Consider a material with an optical absorption coefficient at 550 nm of $\alpha = 10^5$ cm^{-1} and a resistivity $\rho = 1.7 \times 10^{-8}$ Ω m. What is the optimum thickness (t_{opt}) of this material for transparent conducting applications according to Haacke's proposal? What will be the Figure of Merit of this material? [20%]

(c) The material in 4 (b) has a free carrier density $n = 5.66 \times 10^{20}$ cm^{-3}. An application requires a transparent conducting film with 90% transparency at 550 nm, a sheet resistance of 2 Ω $\square^{-1}$ or lower and a wavelength transparency range of up to 1500 nm. Will the material in 4 (b) satisfy the requirements? Justify your answer. [30%]

(d) Consider four liquid dispersions (A, B, C, D) of silver nanowires with the same mean-square diameter and the lengths shown in Table 1:

	A	B	C	D
Length (nm)	120	50	70	80

Table 1

Assuming the nanowires as sticks and their uniform deposition as thin-films, calculate the critical percolation threshold for the four thin-films in terms of the number of nanowires per unit area. [25%]

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Numerical Answers:

2(b) J_1 = 27.31 kA m^{-2}, J_2 = 56 A m^{-2}

2(d) η = 2

4 (b) T = 10 nm, FOM = 0.217

4 (c) λ_p ~ 1400 nm , sheet resistance 1.7 Ω/sq. Does not satisfy the transparency range requirement.

4 (d) N_{CA} = 3.96 × 10^{10} / cm^2, NCB = 22.84 × 10^{10} / cm^2, N_{CC} = 11.65 × 10^{10} / cm^2, N_{CD} = 8.91 × 10^{10} / cm^2