Cribs – 4B22 Academic year 2018

ANSWERS:

Q1.

a)

Silver nanowire:

Shape is good to achieve a percolated network

Solution processable, and hence, easier to deposit on to target substrate (for example, by spray coating)

Easier to fabricate stretchable transparent conductors such as PDMS, shows good repeatability under strain.

Adhesion failure on rigid substrates is a problem.

Electromigration can reduce the lifetime of conductors

May contribute to hazing/optical scattering losses.

CVD graphene:

Continuous film

Challenging to deposit on to the target substrate

Challenging to fabricate continuous transparent conductive films on stretchable substrates.

Shows good repeatability under strain.

Adhesion failure on rigid substrates for single layers is not a major concern

No electromigration

Defect free films do not contribute to scattering losses.

Solution processed graphene

Physical structure does not support good percolation

Solution processability is somewhat achievable.

Deposition to target substrate to achieve a percolated network is generally challenging.

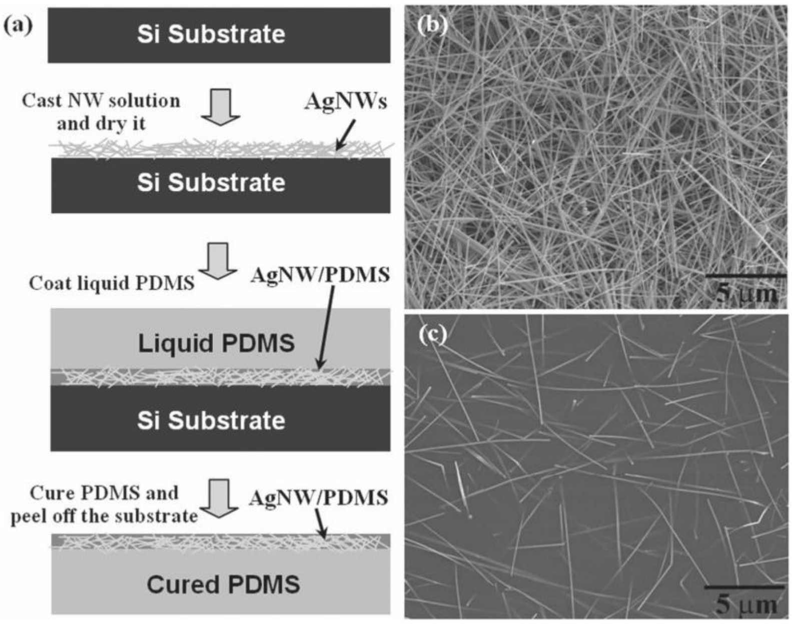
Challenging to fabricate continuous transparent conductive films on stretchable substrates.

Shows moderate repeatability under strain.

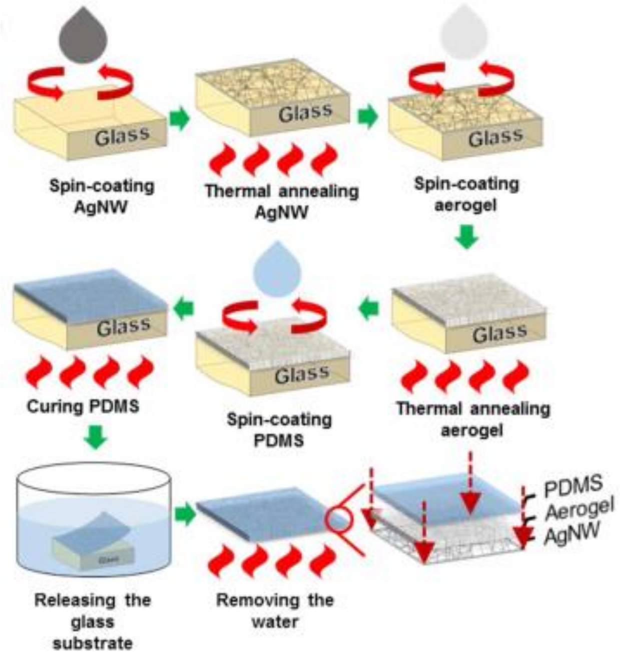
Adhesion failure on rigid substrates for thicker layers may be a moderate level concern

No electromigration

Minor contribution to scattering losses may be observed.



OR



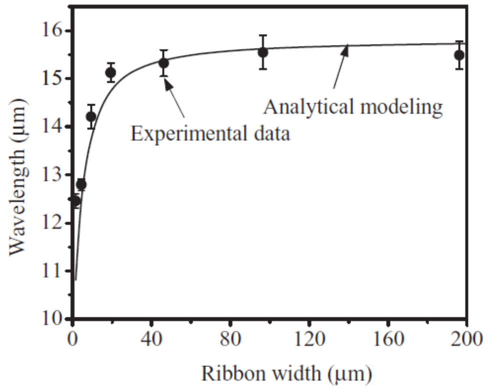
b) The flat ribbons are first chemically bonded to a pre-strained compliant substrate. When the pre-strain is released, the ribbons are compressed to generate the wavy layout through a nonlinear buckling response. These wavy layouts can accommodate external deformations through changes in wavelength and amplitude.

For a stiff thin film ribbon a wavy profile forms, with the out-of-plane displacement being:

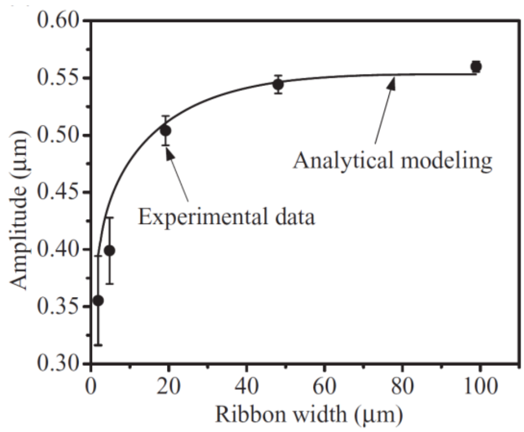
$$w = A\cos\left(\frac{2\pi x_1}{\lambda}\right)$$

Where x1 is the coordinate along the ribbon direction, k = 2 π / λ is the wave number, and A and λ are the amplitude and the wavelength of the buckling wave.

For W < 20 µm the λ is influenced by the width, due to strain energy minimisation.



For W < 50 µm A is influenced by the width due to strain energy minimisation.



c) Students can choose the description of two of the following list of semiconducting materials deposited by low temperature:

- **Hydrogenated a-Si:H films:**
- **Low temperature Nanocrystalline Silicon**
- **Transition Metal Oxides**
- **Organic semiconductors**

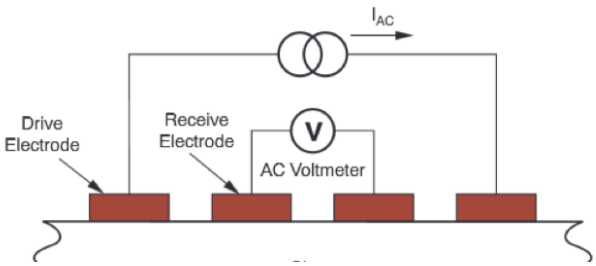
d)

The candidate may start outlining that the BIVA is a statistical model of the hydration status of a person, which links the height (Ht) normalised resistive R and reactive Xc components, from bioimpedance measurements.

The ellipses show 50%, 75% and 95% tolerance regions of normal values of the bioimpedance in a relatively large population of individuals. The bioimpedance measurement vector falling outside these regions there is evidence of a significant change in the body fluids or body lean masses.

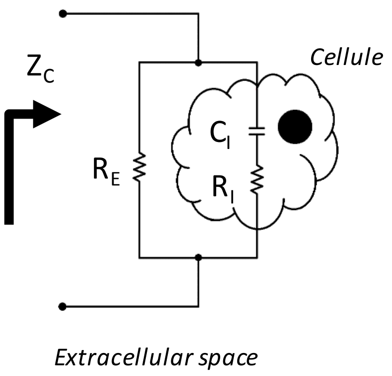
A = decrease of body fluids mass, B = decrease of body lean mass, C = increase of body fluids mass, D = increase of body lean mass.

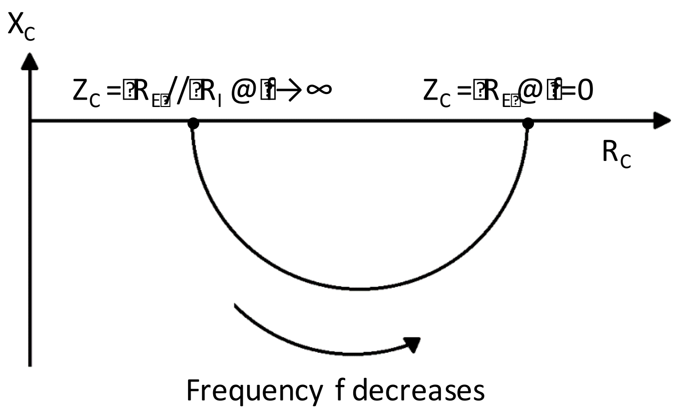
A possible non-invasive 2-point method for measuring the bioimpedance is from skin by dry or gel-assisted pad electrodes, according to the following simplified schematic:



This method works by injecting a sinusoidal AC current into the tissue through the drive electrodes. The AC current creates a potential difference across any two points between the drive electrodes. This potential difference obtained is related to the tissue impedance between the sense electrodes. The equivalent resistance (or the module of the impedance at a given frequency) is defined as the ratios of the voltage difference between the two receive (sense) electrodes and the current that flows through the tissue.

The correlation between the operating frequency and the measured impedance is correlated to the values of the resistance and reactance corresponding in the cellular and extracellular space of the body tissue, according to the following model:





Q2.

a) In this model **electrons in a solid behave like a gas**. Each atom contributes one electron to the gas, and the electrons obey **Fermi-Dirac statistics** (i.e. this leads to the Fermi-Dirac electrons velocity distribution as opposite to Maxwell-Boltzmann distribution).

The vectors in the reciprocal lattice exist in the momentum space (or k-space) which is the set of all momentum vectors a particle can have.

The electron's wavefunction is an oscillating wave with momentum k. The electron energy is proportional to k^2 for free electrons, thus making it intuitive to plot E vs k.

The limitations are that this model **cannot model the appearance of band gaps**. Because the **ions in a perfect crystal are in a regular periodic array**, electrons in crystals can be studied by considering the problem of an **electron in a periodic potential U(r)** with the periodicity of the Bravais lattice, **U(r+R)=U(r)** for any Bravais lattice vector **R**.

b) Assuming that the mobility of the induced carriers is μd, the current lD is given by

$$I_D = Wq\mu_d n(x)E_x$$
$$= \mu_d W C_g (V_G - V_{TH} - V(x))\frac{dV(x)}{dx}$$

Integrating this along the channel,

$$\int_0^L I_D\,dx = \mu_d W C_g \int_0^{V_D} [(V_G - V_{TH}) - V]\,dV$$

The condition is that the gate voltage is greater than the threshold voltage.
The condition is $V_d \sim V_g - V_{th}$

c)

d=25um, V_{screen}=0.1 m^3, K_p=0.6, (η) ρ_{max}=600g/l

$d = V_{screen} k_p\, \phi/\rho$ => ϕ=0.25

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

Q3.

a) Discussion about transport in conjugated polymers.
$\mu = \frac{De}{k_B T}$ where $\mu \propto T^{-\nu}$ where $1 < \nu < 3$.

Where the diffusion coefficient $D=v\lambda_m$ might also be temperature dependant, where v is the drift velocity and λ_m is the mean free path. At higher temperatures more phonon modes are activated and the polarons will have a smaller mean free path. In conjugated polymers, for example, at temperature above the Debye temperature, the number of activated phonons increases linearly with temperature, more scattering is likely to occur, which gives rise to a $D \propto T^{-1}$ and thus µ which scales as T^{-2}.

b)

Eg = 1.5 eV, Ka~ 1.323 rad.

d)

$\sigma_{VRH}(T)=\sigma_0 \exp\text{-}(T_0/T)^{1/d+1}$, where d=3

$\sigma_{VRH}(T)=\sigma_0 \exp\text{-}(T_0/T)$, when d=1

Due to the most difficult hopping path limiting the conductivity in the 1D case, unlike the optimal hopping path between the parallel chains in the 3D case.

Q4.

a)

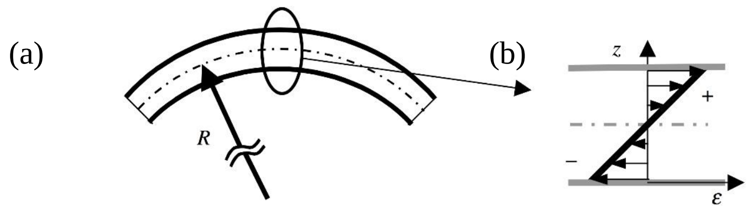


Figure 1: (a) sketch of the bent polymer film. (b) linear strain variation across the thickness of the polymer film.

b)

Assumptions made: Linear mechanics, pure bending, and no-slip boundaries between the layers, and thus, zero shear deformation in the layers. No large mismatch between the elastic modulus of the layers.

c)

Free carrier plasma resonance frequency (f_p) is the frequency defined by the rapid oscillations of the electron density in a conducting medium such as metals or plasma. It is defined as:

$$\omega_p = 2\pi f_p = \sqrt{\frac{ne^2}{\varepsilon_0 m^*}}$$

where

n is the free carrier density

e is the electron charge

m^* is the effective mass of electron (rest mass in this case)

e_0 is the permittivity of free space

This usually defines the upper cut off wavelength of transmission of conducting mediums by the following relation:

$f_p = \frac{c}{\lambda}$ where c is the speed of light and λ is the upper cut off frequency.

With the given free carrier density, f_p can be written as

$$f_p = \frac{\sqrt{3.21 \times 10^{21}} \times 1.602 \times 10^{-19}}{2\pi \times 2.84 \times 10^{-21}} = \frac{c}{\lambda}$$

$$\lambda = 589.64 nm$$

Thus, the material cannot be used as a transparent conductor for touchscreen applications as it will be opaque above 589.64 nm.

d)

1 gm of ink contains: 800 mg of water (0.8ml) and 200 mg (0.02 ml) of silver: 0.82 ml of ink (considering immiscibility).

Each silver nanowire volume: pi*r2*h

Number of nanowires present in 0.82 ml of ink (200 mg): 1.69*1012 (2.069*1012 in 1 ml of ink)

Percolation for a 1 cm by 1 cm area:

l is 60 * 10-4 cm

Nc = 158611

For 10 cm by 10 cm coverage:

Nc = 1.586*10^7

Minimum volume of ink required to achieve percolation: 7.66 ul.

ASSESSOR'S COMMENTS, MODULE 4B22

Q1:

A popular and straightforward question, well-answered by most candidates who chose it except for section (d), which only few students fully answerer. Some gave incorrect list of "resistance and reactance of human body" in (d,i), while some candidates found difficult the description of a non-invasive method to measure bio-impedance required for (d, iii).

Q2:

Less popular question where most of the candidates who attempted this question gave an incomplete answer for (d), but almost everyone could do (b) and (c). Mostly reasonably good answers in (a).

Q3:

In this case, most of the attempts to this question gave incomplete answers to (b), with only very few excellences. Most could do the standard bookwork of part (a) and (d). A good number of candidates gave the incorrect answer for the access resistance in staggered TFTs in (c).

Q4:

Most of the candidates who selected this question produced very good solutions, except for part (d) where some miscalculated the volume of dispersion required to achieve percolation quite often as a consequence of incorrect unit conversion.