Q1)

a) **Bookwork**

i) Photolithography:
• Defective mask, e.g., scratches, cracks, bubbles
• Leftover chemicals or photoresists.
• Clean room residues.
• Dust, water marks on mask.
• Contamination from photoresists/ etchants (if wet etching used).

ii) Plasma processing
• Build up of charge produced by plasma that leads to large current flowing through the dielectric causing wearout damage.
• Build up of charge leads to charge trapping.
• Film adhesion damage due to photon and chemical attacks.
• Damage to surface of semiconductor.

iii) Ion Implantation
• Contamination due to ion species, Fe, Ni, Cr and Mo.
• Ion-beam-sputtered atoms from photoresists, vacuum hardware,
• Wrong ion may be implanted. Selection of ion species is based on m/q variations.
• Variation in the depth implantations leading to junction depth variations.

b) **Bookwork**

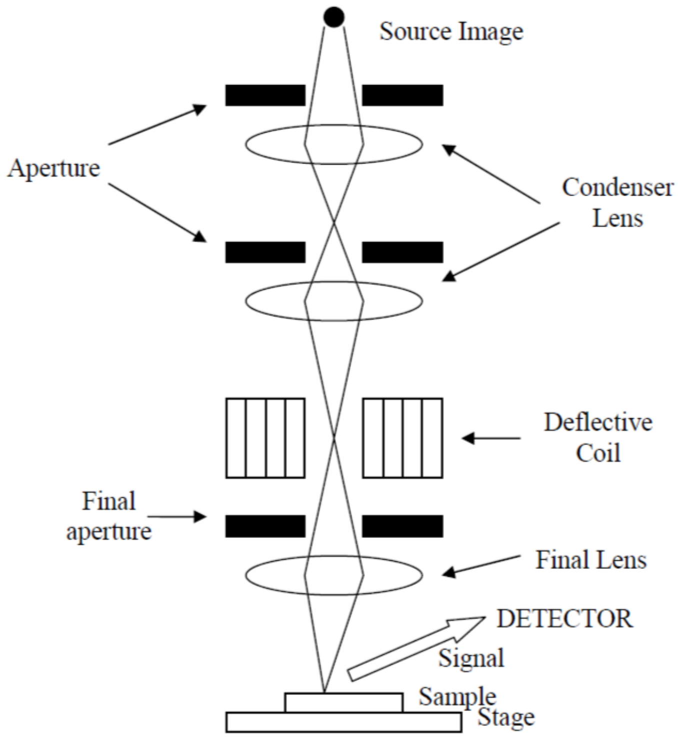
- Metals diffuse rapidly in semiconductors, and have low solubility leading to precipitation of metal silicides at lattice defect sites (e.g. $FeSi_2$) when cooled.

- Can act as minority carrier generation-recombination centres (levels within energy gap).

- Metal precipitates can lead to generation of dislocations and stacking faults, and can enter existing dislocations/SFs making them more conductive.

c) **Bookwork**
[0D] – intrinsic/extrinsic point defects such as vacancies, interstitials, impurities,
[1D] – dislocations (edge/screw)
[2D] - stacking fault, grain boundaries
[3D] – voids, precipitates of point defects

d) **Bookwork**



e) **Bookwork**
3 of the following…

Voltage contrast:

When a device is powered up within SEM the surface potentials alter the secondary electron emission. Electron detector is biased positively to collect the emitted electrons. The more negative the surface potential is, the more the secondary electrons are emitted, leading to a brighter image. Therefore can detect and locate shorts or breaks in interconnections.

EBIC:
Locates the junction of a diode, in a powered device. In the presence of defects that serve as non-radiative recombination centres, the current induced by injected electron beam probe is smaller. Therefore areas with defects correspond to smaller currents and will appear darker in the EBIC image. Shows up regions of enhanced recombination associated with defects around the junction.
An electron beam is injected into a semiconductor to generate minority carriers. These carriers then diffuse from their generation points and recombine at a rate determined by their minority carrier recombination lengths. Therefore the current induced by the minority carriers is small in the absence of electric field.
In a p-n junction, electrons and holes generated within the depletion region are separated by the electric field. As they drift, external current is induced at the contacts. This induced current is largest at the junction and decays with distance away from the junction as carrier collection efficiency drops. Therefore variations in the currents can be translated into variations of contrast in an EBIC image.
Can be superimposed on secondary electron image to correlate spatially.

Cathodoluminescence:

High energy electrons impinging on a localized area of material create more electron-hole pairs, which may recombine and emit light. Light collected and transferred to a detector. Can then map optical activity in structure on the nanoscale, picking up any defects (e.g. dislocations). Defects compete with collection of carriers by the junction and with radiative recombination – reducing CL intensity. Can be applied to materials, not necessarily devices.

EDX:

X-rays have energies specific to the atoms which emit them and can be analysed to identify the atoms in the sample. Can show e.g. depletion of Al in electromigration, or analyse contaminants/protrusions on or close to the surface.

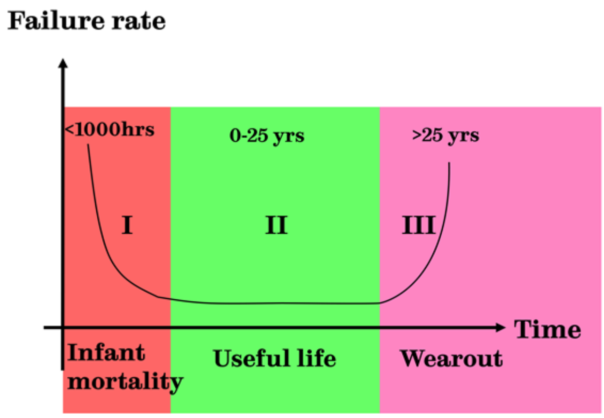
Detection of back-scattered electrons:

These electrons have approx the same energy as the incident electrons (elastic collision). Contrast variations depend on atomic number because intensity of detected signal increases with atomic number. Back-scattered electrons penetrate deeper than secondary electrons, exposing electromigration failures beneath passivation layers. Can show contrast between areas of different chemical composition.

Q2)

a) **Bookwork**: Reliability is the probability of a system or a product performing its intended function over a stated period of time under specified conditions. Important to give confidence to customer and establish trade-off between performance, reliability and cost.

b) **Bookwork**



I. Infant mortality: e.g. manufacture defects, poor manufacture control, design fault, improper handling/packaging, incomplete testing etc.

II. Useful life: random, unavoidable excessive loads, electrical noise, ESD, production defects not screened out by burn-in, etc..

III. Wearout: material or product fatigue, subtle microscopic defects grow over time, corrosion, insulator degradation, metal/defect migration, shrinking/cracking of plastic materials etc..

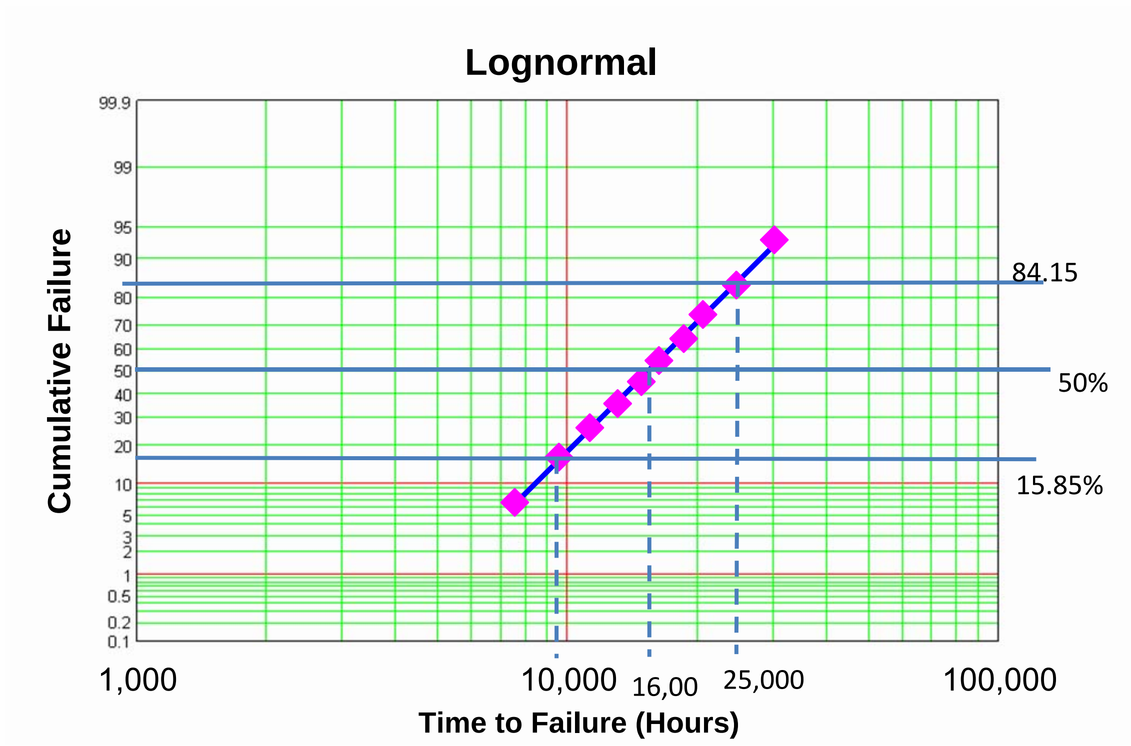
c) **Bookwork:** Region I: Weibull, Region II: Exponential, Region III: Normal

However, lognormal or Weibull analysis can be used for all regions to determine the region you are operating in through extraction of shape parameter.

d) i) **Analysis:**

Rank, i	Failure time (hours)	$F_i(t)$
1	7500	6.730769
2	9500	16.34615
3	11200	25.96154
4	13000	35.57692
5	14750	45.19231
6	16200	54.80769
7	18500	64.42308
8	20500	74.03846
9	24500	83.65385
10	30000	93.26923

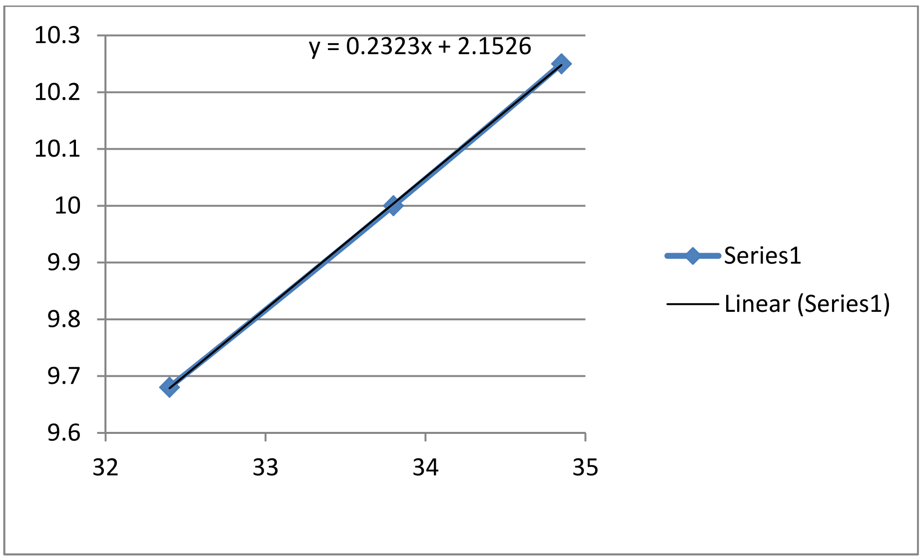
ii)**Analysis:**



iii) **Analysis:** Shape parameter, σ = ln(25,000)-ln(16,000) = 0.44. This is < 0.5 therefore we are in the wearout region of the bathtub curve with an increasing failure rate with time.

iv) **Analysis:** MTTF ~16,000hours

v) **Analysis:**



E_a = 0.2323, A=8.6. Using Arrhenius equation:

$$MTTF\ (T) = A \exp\left(\frac{E_a}{kT}\right)$$

Input A=8.6, E_a=0.2323, k=8.617343x10^{-5}, T=313K to get 47,300 hours ~5.3years.

Q3)

a) **Bookwork:**

EOS: Excessive voltage can be induced during power supply switching, power supply line variations and lightning surges. Improper handling of devices such as use of wrong testing conditions can also cause EOS. EOS usually leads to development of hot-spot which initiates a thermal runaway. Eventually shorting of junction or melting of metallisation (open circuit) cause the device to fail.

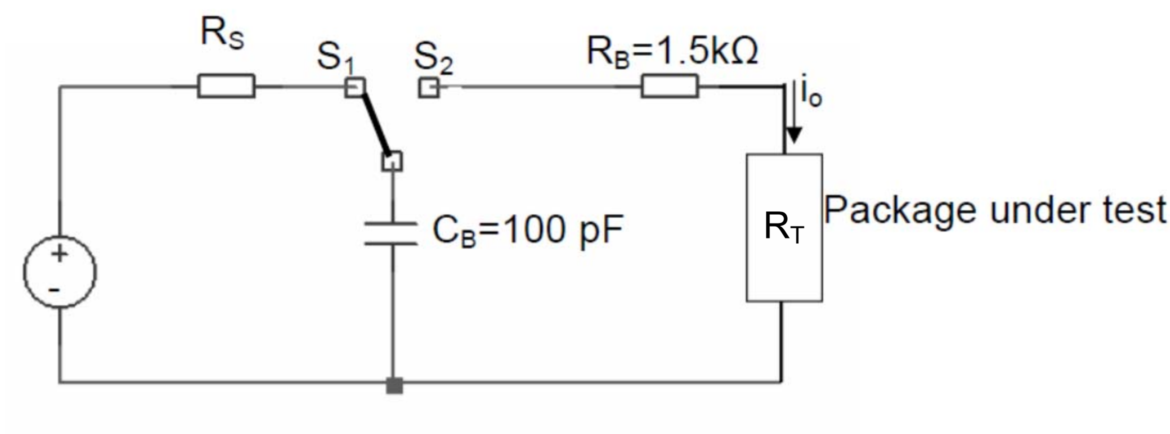
ESD: Static charge buildup resulting from e.g. triboelectric rubbing, . ESD can induce a high voltage that can cause junction spiking via electromigration, melting of sections of device, or breakdown of dielectrics, interconnects.

<u>EOS:</u>
• Voltage involved is usually tens to hundreds of volts.
• Caused by excessive applied field, mishandling or voltage pulses
• Millisecond to microsecond

<u>ESD:</u>
• Voltage is usually thousands of volts
• Generated by static charge, signal
• nanosecond

b) **Bookwork and analysis**

i)



ii)

$R_T = 20\Omega$

$\tau = C_B(R_T+R_B)$

$\tau = 100\times10^{-12}(25+1500) = 0.1525\mu s$

Therefore $5\tau = 0.76\mu s$

iii) $i_0 = V_{HBM}/(R_T+R_B) = 4700/(25+1500) = 3.08$A

iv) Power density discharged = $\langle P\rangle/A_0 \sim R_T i_0^2/(10A_0) = 25(3.08)^2/[10(5\times10^{-7})] = 47.5$MWcm^{-2}

c) **bookwork**:

MOSFET:
Radiation with modest energy can generate electron-hole pairs in the SiO2 layer. Since the ionization energy is ~17eV, 1 rad radiation can generate 10^{13} pairs/cm^2. Usually mobile electrons are extracted but holes are trapped in the oxide layer or at the Si/SiO2 interface. These trapped charges reduce the threshold voltage by Q_{ox}/C_{ox} (Q_{ox}: charge concentration, C_{ox}: oxide layer capacitance.). As a result, the MOSFET can be turned on without an applied voltage.

GaAs FETs
No gate oxide, therefore do not suffer carrier trapping problem. However, the radiation generates electron-hole pairs in bulk semiconductor leads to leakage current that degrades the gain. In addition the radiation of 10^{18} rad is required to cause these effects in channel with high doping levels.

Laser diodes:
Radiation generates electron-hole pairs and dislocations in lasers, which act as non radiative recombination centres that increase the current threshold of the laser or generate dark line defects. In addition many lasers incorporate a photodiode to monitor laser power. Since the photodiode can also be affected by radiation, the monitor diode will degrade hence affecting the laser performance.

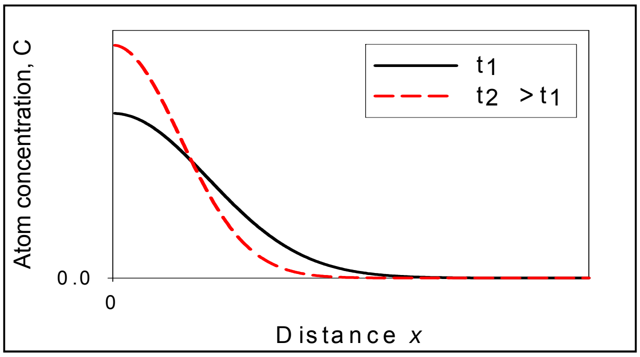
Optical fibres:
Radiation creates electron-hole pairs which are trapped in defect sites in the fibre creating new energy levels that absorb light. This increases the loss which can be observed from darkening of the fibre.

Q4) **All bookwork**

a)

Fick's law states that a concentration gradient *dC/dx* in the *+ve x* direction causes mass transport of atoms with flux J_m (atoms/cm^2/s) in the *–ve x* direction, where *D* (cm^2/s)is the diffusion coefficient (measure of extent of mass transport).

$$J_m = -D\frac{dC}{dx}$$



The diffusion coefficient, which is a measure of the extent of mass transport, depends on: nature of atoms/matrix, transport path (whether bulk lattice, grain boundary, dislocation, surface, interstitial etc.), temperature, concentration of diffusing species.

b)

Atoms can:

1) swap places with vacancies,

2) hop within the dislocation cores,

3) migrate along grain boundaries

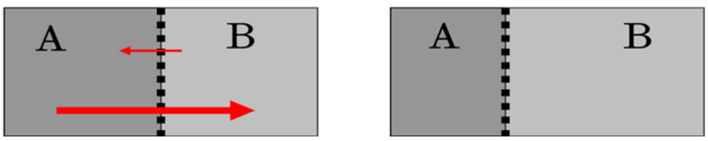
4) skip along the surface.

Require successively less energy than transport in bulk and are more likely to cause potential short circuits

c)

Interdiffusion can cause reliability problems in solder joints and semiconductor contacts.

Example: Equal volumes of A and B. As heated, more atoms flow A→B. Difference in diffusion flux → net flow of atoms, shifting an inert marker to the left.



v_{eff} of marker plane motion,

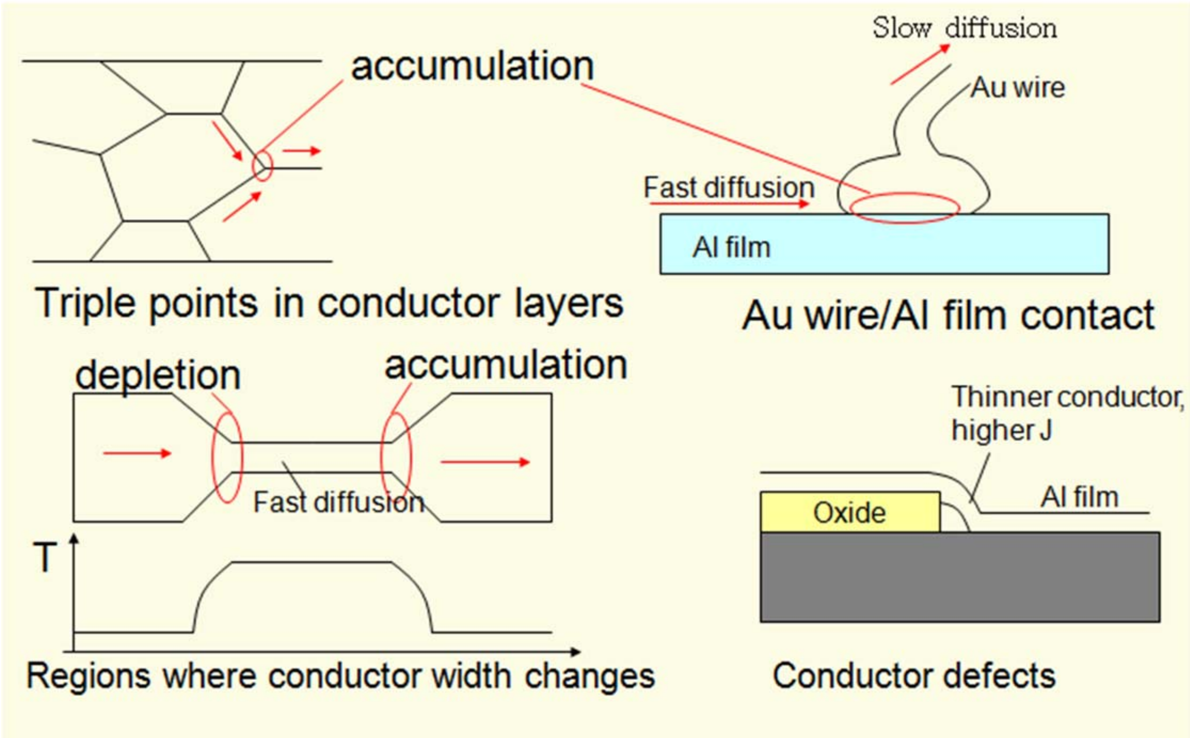
$v_{eff}=(D_A-D_B)dC_A/dx$

Not only effecitive interface migration, but voids may also form as flux of atoms is equal to the flux of vacancies. Therefore, vacancies build up on the A side and are depleted on the B side. Enough vacancies may condense into voids.

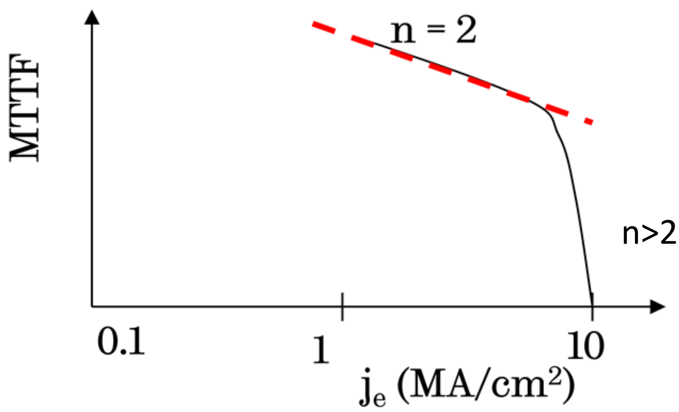
d) Three of.....

Types of failure mechanisms	Possible Causes
Ball bond lifting	Contamination on bond pads, incorrect bonding parameters, Kirkendall voids, bond pad corrosion
Wedge bond lifting	Contamination, incorrect parameter settings, corrosion
Ball bond neck break	Incorrect parameter settings, incorrect wire loopings, die to package delamination, excessive thermal treatment (bamboo grain formation)
Wedge bond heel break	Incorrect parameter settings, package delamination, incorrect wire loopings, leadfinger to
Bond to metal short	Incorrect parameter settings, incorrect bond placement, insufficient bond pad-to-metal distance
Bond to bond short	Incorrect parameter settings, incorrect bond placement, insufficient bond pad-to-bond pad distance
Wire to wire short	Incorrect wire looping, insufficient wire-to-wire distance
Cratering	Incorrect parameter settings, excessive bond pad probing

e) Three of....


accumulation
Slow diffusion
Au wire
Fast diffusion
Al film
Triple points in conductor layers
Au wire/Al film contact
depletion
accumulation
Fast diffusion
T
Thinner conductor, higher J
Oxide
Al film
Regions where conductor width changes
Conductor defects

f)


MTTF
n = 2
n>2
0.1
1
10
j_e (MA/cm^2)