

Q1.

- a) i) gold wire displacement can be observed with X-radiography prior to opening package.  
ii) intermetallics best observed using IR-microscopy (SAM only really useful for voids).  
iii) popcorn cracking using SAM (no removal of packaging needed)  
iv) Electromigration under oxide observed using IR, reflected light from metals shows contrast. SAM doesn't have the resolution needed.  
Don't need SEM for any of these or methods requiring packaging removal.

- b) CL and EBIC can be used. In CL, high energy electrons create more electron-hole pairs in semiconductors which may recombine and emit light. In EBIC, an electron beam injected into a semiconductor generates carriers within the depletion region, which are separated by the electric field. As they drift, external current is induced at the contacts.  
EBIC is applicable to fabricated devices where as CL enables partly fabricated structures and starting materials to be examined. EBIC gives just a signal whereas CL can give spectral character. Both can map out optical activity on nanoscale, detecting any non-radiative defects in and around the junction.  
Their operation can be taken from the lecture notes.

- c) Possible failure analysis process flow:

Examine prior to opening

Microscope (corrosion, whiskers)

X-ray radiation (internal geometry, physical defects, bond wires, solder)

IR microscopy

Package opening/encapsulation removal

Chemical etch, polishing (check mechanical damage, corrosion, misalignments)

Internal exam

SEM.

Selective layer removal

e.g. ESD, EOS, sub surface evidence. Layer removal by ion milling

SIMS, TEM

Locate, ID failure cause/mechanism

Q2.

- a) These are intrinsic point defects in compounds.

Schottky defect – pairs of opposite sign

Frenkel defect – vacancy + interstitial

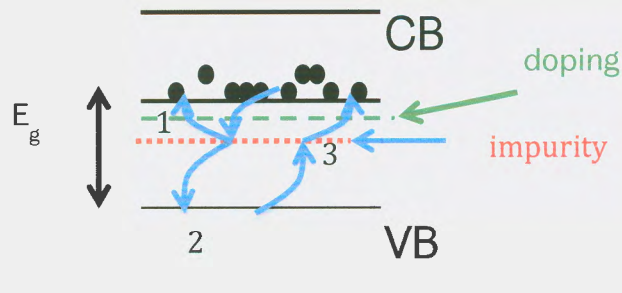
- b) i)  $E_a = 0.27\text{eV}$

ii) at 1000K,  $C_v = \exp(-E_a/kT) = \exp(-0.27/1000k) = 0.04 \text{ m}^{-3}$

- c) Defective impurities have deeper ionization energy than dopants – deep levels

Deep levels can act as:

1. traps (if re-excitation to CB possible)
2. recombination centres (if carriers drop to VB)
3. or generation centres (if electron excited VB→defect→CB)



d) Point defects produce a lattice distortion. Amount of distortion depends on space between atoms in the lattice and the size of the atom introduced. Interstitial volume < 1 atomic volume → interstitials produce larger distortions → large  $E_a$  → less prevalent

e) Origins of metal impurities:

Sources of contamination include furnaces and epitaxial reactors, ion implanters, plasma, reactive ion etching, etching chemicals, wafer handlers etc

e.g. Cu, Fe, Ni and Cr can diffuse rapidly ( $D \sim 10^{-6} \text{cm}^2/\text{s}$ ,  $E_a < 1 \text{eV}$  at  $500^\circ\text{C}$ ) in Si (P, B, As:  $D \sim 10^{-13} \text{cm}^2/\text{s}$ ,  $E_a \sim 3\text{-}4 \text{eV}$ ) at high temperatures, creating impurity energy levels in the gap.

Metal has low solubility in Si leading to precipitation of metal silicides at lattice defect sites (e.g.  $\text{FeSi}_2$ ) when cooled.

Many metals act as minority carrier generation-recombination centres (levels in gap)

Metal precipitates can lead to generation of dislocations and stacking faults.

Metals enter existing dislocations/SFs → more conductive

Difficult to avoid. Can use gettering to remove metal contaminants from the active region of a device.

3)

a) MTTF  $\sim 18000$  hours

b) shape parameter =  $\ln 18000 - \ln 5500 \sim 1.18 \sim 1$  which describes the constant failure rate useful life region of the bathtub.

c)

i)  $AF = \text{MTTF}(T_1) / \text{MTTF}(T_2) = \exp[E_a/k(1/T_1 - 1/T_2)]$

$32000/18000 = \exp\{E_a/k[(1/333 - 1/353)]\}$

which gives  $E_a = 0.29$

ii)  $\text{MTTF}(373\text{K}) = A \exp(E_a/kT) = \exp(0.29/k373) = 8288$  hours. So MTTF  $\sim 8000$ , therefore  $\sim 50\%$  of devices are still yet to fail.

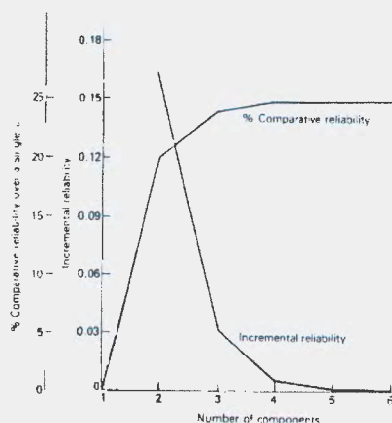
d)  $MTTF = 1/\lambda_0$   
 $MTTF = 8288\text{hrs}, \lambda_0 = 0.000121\text{ hrs}^{-1}$   
 $F(\text{exp}) = 1 - \exp(-\lambda_0 t)$

Probability of failure between 8,000 and 10,000 hours =  
 $1 - \exp(-\lambda_0 \times 10,000) - 1 - \exp(-\lambda_0 \times 8,000)$   
 $= 0.7 - 0.62 = 0.08$

e)

Number of components	$R_p$	% change
1	0.75	
2	0.9375	25
3	0.984375	31.25
4	0.9961	32.8
5	0.99902	33.2

This takes similar form to that in the notes:



4)

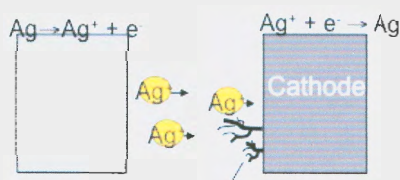
a) Si atoms diffuse along GBs of Al film to create voids. Al atoms counter diffuse into Si, filling the Si depleted regions. However, due to poor solubility of Al into Si, Al precipitates in the form of conducting filaments that shorts the junction or creates high electric field at the tip of the filament that causes local breakdown.

b) Si added to Al to eliminate Al-Si interdiffusion process while Cu added to increase activation energy of the metal to reduce electromigration.

c) When Al-Si alloy cools, Si precipitates to form p-doped Al islands that increase contact resistance. Since Al and Si have different potentials in the electrochemical series, galvanic corrosion occurs in the presence of an electrolyte and bias, giving rise to a change in contact resistance and open/short circuits. Alternatively, adding Cu increases the hardness of the alloy making it difficult to etch the metal and reduce the reliability of bonding.

d) Interconnect degradation – hillocks and whiskers  
Minimize by: short conductor, single crystal, bamboo structure, multi-layers, refractory layers etc as described in notes.

e) electrolytic migration is:



- 1) Ag metal ionically removed.
- 2) A dc voltage (1-100V) exist between the anode and cathode. Ag migrates in E field (requires presence of electrolyte).
- 3) Ag redeposits elsewhere

For electrolytic electromigration to occur:

- Anode must easily form ions
- Metal as cathode nearby
- DC voltage between anode/cathode (1-100V)
- Presence of moisture/water on substrate surface to provide electrolyte.

f) Corrosion in the atmosphere, without the presence of a bulk electrolyte.

The necessary electrolyte can come from condensation from the atmosphere.

When relative humidity is at  $\sim 60\%$ , an extremely thin film of moisture tends to form on metallic surfaces, leading to the start of corrosion.

As  $\text{RH} \uparrow$  moisture film thickness  $\uparrow$  (e.g. as  $T \downarrow$ ).