**Solution for EEE6008 2006/07**

Q1.

**Calculation:**

a) The stress developed is given by

$\sigma = \alpha E(T - T_o)$,

where

$\alpha$ is the coefficient of thermal expansion,

$E$ is the Young's modulus

$T$-$T_o$ is the temperature difference.

We have $\sigma = 4\times10^{-6}\times160GPa\times195 = 0.12GPa$.

Since the edge is at higher temperature, the Si film would tend to expand but is restricted by the substrate. Therefore it is effectively under compressive stress.

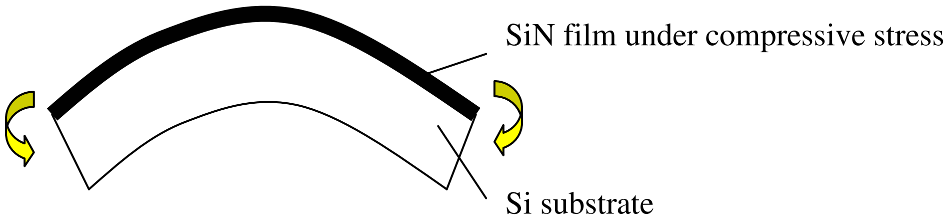
**Calculation and bookwork:**

b) i) The thermal stress developed is

$$\sigma_f = \frac{E}{1-\upsilon_f}\left[\alpha_f - \alpha_s\right]\left[T - T_o\right] = \frac{158GPa}{1-0.25}\left[(2-4)\times10^{-6}\right]\left[300-27\right] = -0.115GPa.$$

(assume that room temperature is 27°C).

The film is under compressive stress since $\alpha_f < \alpha_s$.




**More demanding bookwork and understanding:**

c) i) In the presence of high current density, the electron movement induces a force that moves an atom into neighbouring vacancy. Over a long period of time high current densities cause migration of atoms along the conductor.

Electromigration can lead to formation of hillocks, whiskers, void, thinning of metals, localised heating and cracking of passivation film. (any two)

ii) The stress gradient in thin metal can generate a force to counter the atom movement due to electromigration. This is known as the Blech effect.

Under high current densities electromigration causes migration of conductor atoms from cathode to anode. If the conductor is shorter than a critical length, a stress gradient can develop causing a flow of atom from anode to cathode. Therefore this counters the electron movement due to electromigration.

Q2.

**Bookwork:**

a) i) Energy dispersive x-rays (EDX) and the back scattered electrons can be used to characterise atomic species.

**More demanding bookwork and understanding:**

The high energy electron beam can promote electrons from the ground state to higher energy states. X-rays are emitted when the electrons are transferred from these high energy states to lower energy states. Since the energy states are specific to atoms, the atoms can be identified by analysing the x-ray spectrum emitted.

**More demanding bookwork:**

Some of the incident electrons are back-scattered by the atom. These back-scattered electrons have energies close to those of the incident electrons. However atom with higher atomic number can produce larger contrast variations thus enabling the identification of the atom.

ii) The potential of the interconnects can alter the secondary electron emissions. The more negative the potential with respect to the electron detector, the more secondary electrons are detected leading to brighter image. This can be used to locate short circuits or open circuits in interconnects.

**Bookwork:**

b) i) When an x-ray beam is focused on a sample with an absorption coefficient, $\alpha$, the intensity of the beam decays exponentially. Different materials have different absorption coefficients. Therefore by comparing the intensity of the x-ray beam across the sample, the intensity ratios between different materials can be processed into images for failure analysis.

ii) Examples of failure mechanisms that can be detected are displaced or broken wire, missing solder ball, large defects in the die attachment and solder bridging.

**Problem and calculation:**

iii) The x-ray beam intensity is $I(x) = I_o\exp(-\alpha x)$ where x is the penetration depth and $I_o$ is the initial intensity of the beam.

$$\frac{I}{I_o} = \exp\left[-((5\times0.1)+(10.2\times0.03))\right] = 0.447$$ for the polymer and Si.

$$\frac{I}{I_o} = \exp\left[-((5\times0.1)+(10.2\times0.03)+(1510\times10^{-4})\right] = 0.384$$ for polymer, Si and gold bond pad (assume a 1μm thick bond pad).

This gives intensity difference of 14.1% which is detectable. Therefore a higher value of $I/I_o$ will be measured when there is an open circuit.

Q3.

**Bookwork:**

a) i) - Dendrite filament growth due to electromigration leads to a short circuit.

- Cracking due to thermal expansion mismatch between the chip and the substrate.
- Void formation in the adhesive due to presence of oxide and contaminants or due to evolution of gas and moisture.

**Bookwork and understanding:**

a) ii) One of the followings

| 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, incorrect wire loopings, leadfinger to package delamination, |
| 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 |

**More demanding bookwork:**

b) i) The popcorn cracking usually occurs during solder reflow of the surface packages. Moisture penetrates into the package via metal-plastics interfaces and is absorbed by the moulding compound. During reflow soldering, this condensed moisture expand to form a pressurised dome of steam which can cause formation of cracks and delamination. This is known as the popcorn cracking. Cracks and delamination provide conditions for accelerated corrosion.

ii) They can be detected using x-ray radiography and scanning acoustic microscopy.

**Bookwork:**

ii) Any four of the followings

wire sweep – due to wirebonds pushed to each other causing short

epoxy void – due to improper curing

die attachement void – due to popcorn effect

wire breaking – due to mechanical stress

passivation and dielectric layer cracking – due to thermal mismatch

bond pad peel off – contaminated surface

corrosion – due to moisture penetration

radiation damage

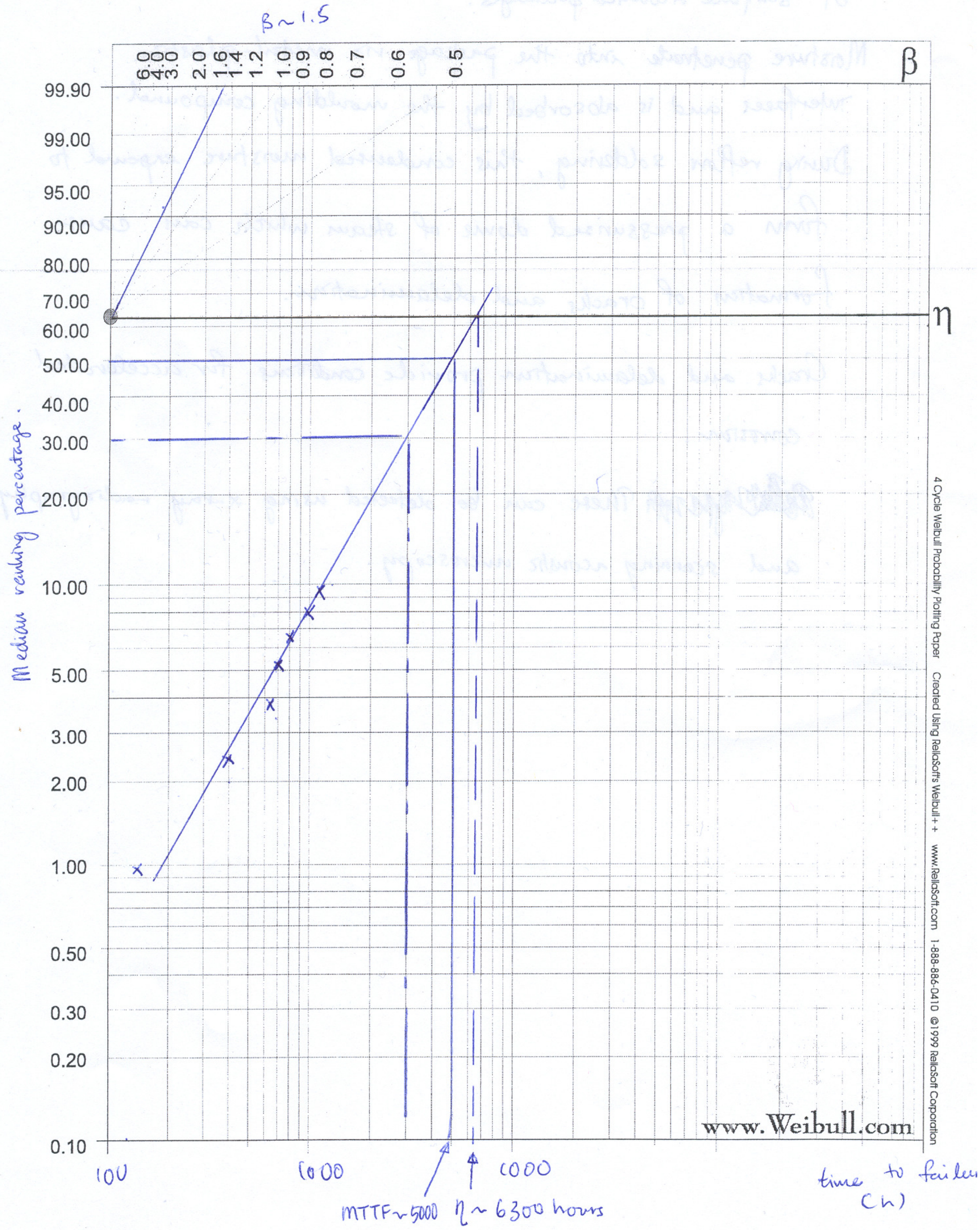
Q4.

| Time to failure (h) | Rank | Median Ranking (%) |
|---|---|---|
| 120 | 1 | 0.99 |
| 395 | 2 | 2.41 |
| 649 | 3 | 3.84 |
| 705 | 4 | 5.26 |
| 800 | 5 | 6.68 |
| 920 | 6 | 8.10 |
| 1150 | 7 | 9.52 |

iii) From the graph $\eta$ ~ 6300 hours and $\beta$ ~ 1.5.
iv) Mean time to failure is ~ 5000 hours. After 3000 hours approximately 30% of the devices will fail.
v) $\beta$ ~ 1.5 suggests that the failure rate is gradually increasing with time. Therefore the possible reasons for failure are time dependent such as electromigration, junction spiking and dielectric breakdown.

b) A Weibull distribution with $\beta$=0.5 will have rapidly decreasing failure rate. This is typical in the infant mortality where the failures are mainly due to poor material quality, poorly fabricated devices and wrong design. To prevent this type of failure it is necessary to improve the purity of the material and fabrication procedures as well as the design. For example gettering can be used to remove impurity from Si.

Q4. a) ii)



β ~ 1.5
β
6.0
4.0
3.0
2.0
1.6
1.4
1.2
1.0
0.9
0.8
0.7
0.6
0.5
99.90
99.00
95.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
5.00
3.00
2.00
1.00
0.50
0.30
0.20
0.10
η
Median ranking percentage.
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100
1000
1000
MTTF ~ 5000
η ~ 6300 hours
time to failure (h)