Data Provided: graph paper

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2013-14 (2.0 hours)

EEE6008 Reliability and Failure

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. a. Atomic diffusion in metal conductors can result from electromigration, where atoms are subjected to an electron wind imparting a force, $F = Z^*q\rho j_e$ on the atoms. A stress gradient force, $F = \Omega\frac{d\sigma}{dx}$ can result from this atomic diffusion, leading to a backflow of atoms.

The following parameters are provided for a given metal:

$Z^* = 1$

$q = 1.6\times10^{-19}$ C

$\rho = 4\times10^{-6}$ Ωcm

$j_e = 1\times10^{5}$ Acm^{-2}

$\sigma = 60$ MPa

Using these parameters, determine what length of conductor is required such that atomic diffusion along the conductor does not take place? **(4)**

b. Describe how atomic diffusion may take place, listing diffusion mechanisms in order of the energy required to move the atoms **(3)**

c. Cu can be added to Al to form Al-Cu alloy conductors, raising the activation energy for Al migration and therefore increasing resistance of the conductor to electromigration. Sketch and describe the additional reliability concern that would arise if the Al-Cu conductor became exposed to moisture? **(4)**

d. Using sketches to illustrate your answer, describe how electromigration can lead to failure at:

i) The bond between an Al conductor and track and a Au wire ball bond **(3)**

ii) Regions where conductor width changes **(3)**

e. Discuss the characterisation method that would be most appropriate for characterisation of electromigration in narrow (μscale) conductors below a SiO2 layer? Your answer should evaluate the suitability of potential alternative methods. **(3)**

2. A Weibull distribution is described by the following cumulative density function, CDF:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right]$$

The following figure plots the results taken from reliability analysis of a set of 15 MOSFETs operated under accelerated life-test at 90°C, of which 12 have reached the end of their life.

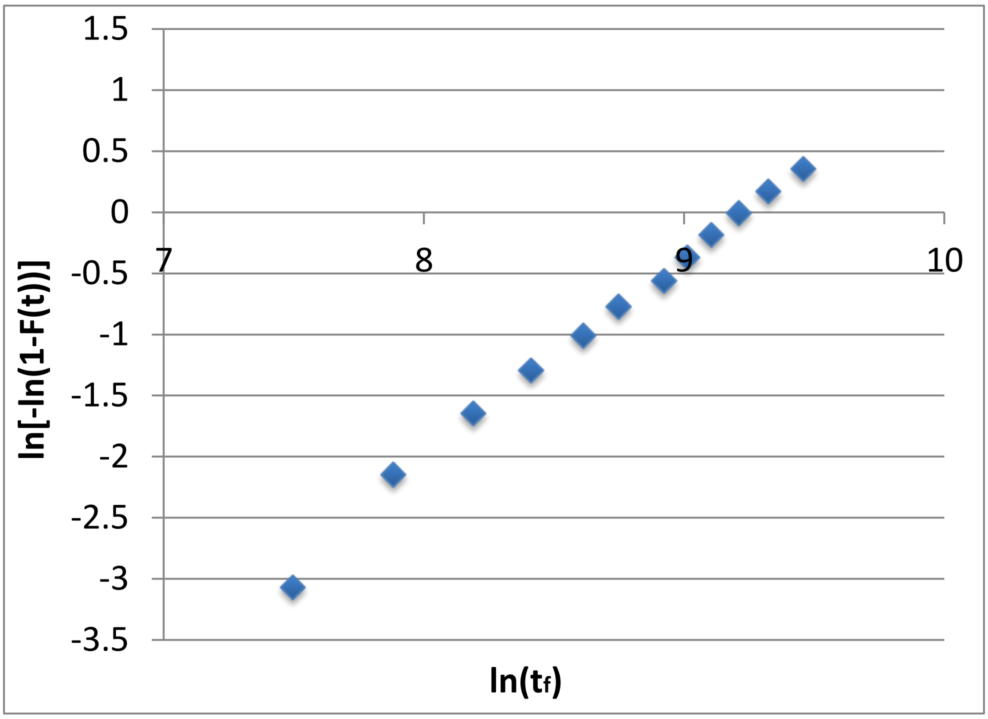

Figure 1 Failure probability plot for a batch of MOSFETs, where F(t) is the median rank, and t_f is the time to failure

a.

i)	Determine the time to 50% cumulative failures	**(3)**
ii)	Determine the shape parameter β	**(3)**
iii)	Obtain the failure rate, λ(t), at 5,000, 8,000, and 12,000 hours and sketch and label the failure rate as a function of time	**(5)**
iv)	Using your answers to parts ii and iii, suggest the corresponding region of the bathtub curve the devices fail within	**(1)**
v)	Predict the percentage of MOSFETs that will have failed after 20,000 hours of operation	**(2)**

b. The MTTF at 60°C and 40°C were determined to be 16,600 and 29,000 hours. Using the graph paper provided, fit the data points at 90, 60 and 40°C to an Arrhenius plot to determine the activation energy, E_a, and use to predict the MTTF at an operating temperature of 23°C. Express your answer in years, and use a scaling parameter, A, = 2.75 (you do not need to extrapolate to obtain this). Use k = 8.617343×10^{-5} eVK^{-1}. **(3)**

c. Describe the possible mechanisms typically associated with the wearout failure of dielectric layers within MOSFETs. **(3)**

3. **a.** Briefly outline 4 mechanisms by which solder joints can fail. **(4)**

b. Calculate the shear strain rate, γ, on a solder ball of height, h_s = 100µm positioned l_c = 100µm from the centre of a GaAs chip, soldered to an AlN submount. The temperature excursion (**Δ**T) was 150°C for 10 seconds (**Δ**t). Use the following coefficients of thermal expansion:

GaAs = 5.7×10^{-6} K^{-1}

AlN = 4.5×10^{-6} K^{-1} **(3)**

c. Outline 2 methods by which solder lifetimes can be increased. **(2)**

d.

Material	Thermal conductivity, $Wm^{-1}K^{-1}$	Coefficient of thermal expansion /°C
Al_2O_3	18	8
AlN	150	4.5
Si_3N_4	25	3.1
Cu	400	17
CuW	170	6.5
GaAs	52	5.7
InP	68	4.6

Table 1. Thermal conductivity and coefficient of thermal expansion data for a range of submounts, together with data for GaAs and InP semiconductor chips.

Answer the following questions with reference to the data in Table 1 above of the thermal properties of materials. Justify your answers with reference to the potential alternatives found in the table.

i) Which submount is most appropriate for low power InP telecoms chips? **(2)**

ii) Which submount is most appropriate for very high-power GaAs chips? **(2)**

e. In flip-chip bonding, chips are mounted such that their active area faces the substrate using fluxless solder bumps. Sketch a suitable chip assembly arrangement and describe the role of the various interconnect materials incorporated. **(4)**

f. Describe how galvanic corrosion, mass transport and shear distortion present potential reliability problems in the flip-chip bonding arrangement. **(3)**

4. **a.** Describe how MOSFETs can suffer radiation damage through ionization from high-energy particles. **(3)**

b. List 3 environments in which radiation could be particularly problematic **(3)**

c. Despite our best efforts to shield packaged modules from the harmful effects of radiation why might we never be able to fully protect chips from exposure to high-energy particles? **(2)**

d. Describe the damage that can be inflicted upon optical fibres by:

i) A moist environment **(2)**

ii) High-energy particle irradiation **(2)**

e. Outline one preventative method for each damage mechanism described in part d. **(2)**

f. A number of reliability issues can affect laser diodes.

i) Describe the process of catastrophic optical damage (COD) in laser diodes and what precautions can be taken to prevent facet damage **(4)**

ii) Why might AlGaAs be more susceptible to COD than InP? **(2)**

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