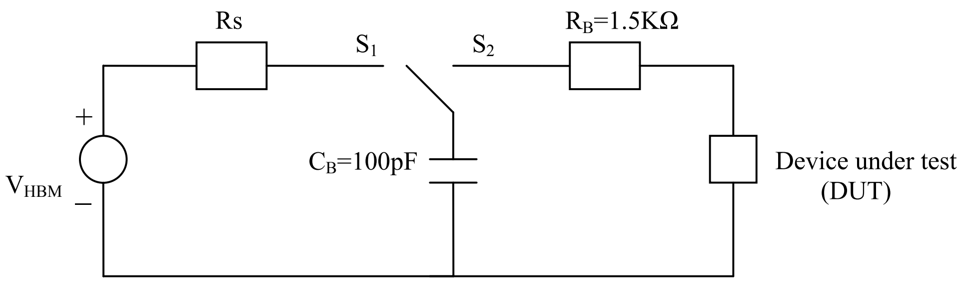
(Q1):

a) The differences between electrical overstress (EOS) and electrostatic discharge (ESD) are listed below:

EOS	ESD
- Voltage involved is usually tens to hundred of volts	- Voltage is usually thousands of volts
- Caused by excessive applied electric field or mishandling	- Caused by static charge build up
- Occurs in ms to us	- Occurs in ns

b)

i)



ii)

V_{HBM}=2500V;

R_d=10Ω;

Time constant: $\tau = (R_d+R_B)\text{x}C_B$

$= (10+ 1500)\text{x } 100\text{x}10^{-12}$

$= 1.51\text{x}10^{-7}$(s)

The discharge will last for about 5 τ = $5\text{x}1.51\text{x}10^{-7} = 7.55\text{x}10^{-7}$s

iii)

The maximum current flow through the diode:

$=V_{HBM}/(R_B+R_d)$

$= 2500/(10+1500)$

= 1.66 A

Current $i(t) = i_0\exp(-t/\tau)$;

Average power dissipated during the period of discharge:

$$= \frac{1}{5\tau}\int_0^{5\tau} i(t)^2 (R_d + R_B)dt$$

$$= \frac{1}{5\tau}\int_0^{5\tau} i_0^{\ 2} \exp(-\frac{2t}{\tau})dt$$

$$= \frac{(R_d + R_B)\times i_0^{\ 2}}{5\tau}[-\frac{\tau}{2}\exp(-\frac{2t}{\tau})]_0^{5\tau}$$

Average power dissipated:

$$= (R_d + R_B) \times i_0^{\ 2} \times [1 - \exp(-10)]$$

$$= \frac{(1.66)^2 \times 1510 \times (1 - \exp(-10))}{10}$$

$$= 416W$$

c) Current density induced =10mA/cm^2

Current induced = 10x10^{-3}x10^{4}x1600x10^{-12} = 1.6x10^{-7} A

Current density into the gate= (1.6x10^{-7})/(1x10^{-12}) =1.6x10^5 A/m^2 =16 A/cm^2

This large current density causes very high electric field of several MV/cm to be established across the dielectric/oxide. Such high field will either cause rapid degradation of oxide or oxide breakdown.

(Q2):

a) Si atoms diffuse along grain boundaries of Al film to create voids. Al atoms counter diffuse into Si filling the Si depleted regions. However because of poor solubility of Al in 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) i) 1 wt% Si is added to Al to eliminate Al-Si interdiffusion process while 0.3~0.5 wt% of Cu is added to increase the activation energy of the metal to reduce electromigration.

ii) When Al-Si alloy cools, Si precipitates to form p-doped (Al) islands that increase the contact resistance. Since Al and Cu have different potentials in the electrochemical series, galvanic corrosion occurs in the presence of electrolyte and d.c bias. This gives rise to a change of contact resistance as well as open and short circuits. (Or incorporation of Cu increases the hardness of the alloy making of difficult to etch the metal and reduce the reliability of bonding).

c) i) Phosphorous is added to improve the fluidity of SiO_2 so that the coverage of step features is improved. However the SiO_2 is usually not perfect. Presence of pin-holes and cracks enables moisture leaks that lead to formation of phosphoric acids. The phosphoric acid causes corrosion of metal via chemical corrosion.

ii) Thermal mismatch between SiO_2 and metal induces stress and metal films, particularly when narrow stripes of metal are used. High level of stress develops at sharp corners leading to formation of voids in the metal films, giving rise to changes in the contact resistance and potentially an open circuit.

d) Examples of failure are short circuits due to formation of hillocks and whiskers and open circuits due to voids.

(choose any 2)

i) Use short conductors so that the back-flow of atoms counters the electron-wind due to high current density.

ii) Use single crystal with no grain boundaries to minimize electromigration.
iii) Use conductor with grain boundary normal to the current flow. This so-called bamboo structure can be achieved using conductor with thickness to width ratio of ~ unity.
iv) Incorporate Cu to increase the activation energy for electromigration.
v) Use multilayer refractory metals such as Ti, W and TiN to reduce electromigration.

(Q3):

a) i) The two main sources of radiation are radioactive elements in materials use in packaging and cosmic rays.
Materials used in ICs contain traces of radioactive atoms that emit alpha particles, beta-particles and γ rays
For example, alpha particles from uranium U^{238} and thorium Th^{232} are found in the earth crust. Therefore, alpha-particles are emitted by metals, gold, alumina and lead frame used.
The alpha particles have energies of 3.8-8.8 Mev can generate electron-hole pairs in bulk semiconductors and dielectrics causing degradation to the devices.

Cosmic rays with energies of 1Mev to 1Gev can cause dislocations in semiconductors as well as generating electron-hole pairs. The cosmic rays can also activate boron atoms in packaging materials to emit alpha particles.

In memory chips the addition electron-hole pairs can cause errors between bits of "1" and "0". However, upon refreshing the additional charges are removed.

Q3: a) ii)

Standard tests based on intrinsic radiation sources are unable to reproduce the soft failures generated by cosmic rays due to difficulties in producing the required neutron spectrum.
Some tests have been carried out in locations such as at mountains and deep underground to make use of actual cosmic rays in these locations. However this is not a practical solution for routine tests. A better option will be to use heavy ions from an accelerator to simulate the effect of incident neutron due to cosmic rays. Some facilities are now available to provide beam that is very clos to the terrestrial neutron spectrum.

b) MOSFET:
i) Radiation with modest energy can generate electron-hole pairs in the SiO_2 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/SiO_2 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.
ii) GaAs FETs have no gate oxide. Therefore do not suffer carrier trapping problem. However, the radiation generated 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.
iii) Radiation generates electron-hole pairs and dislocations in laser. These dislocations 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.

c) Strategies employed involved isolating the devices from electrical continuity with the base semiconductor wafer. Dielectric isolation and silicon or insulator (SOI) has been used. The isolation removes latch-up paths and reduce the volumes around junctions and oxides when carrier generation and trapping occur.

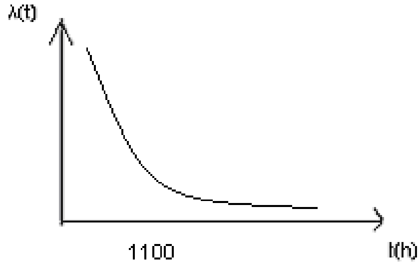
Q4) a) i)

Rank (i)	Failure Time (h)	Fi (t)
1	45	1.2
2	67	2.8
3	90	4.5
4	110	6.1
5	160	7.8
6	180	9.4
7	230	11.1

ii) Graph attached.

iii) From the graph $\sigma \sim 6.1 - 4.6 = 1.5$
OR $\sim 4.65 - 3.25 = 1.4$
Meantime to failure = 1100 hours.

iv) The value of $\sigma = 1.5$ suggests that the failure rate is high at the first but settles to a relatively constant value after 1100 hours.



It can also be seen that 53 of the diodes do not fail after 1000 hours suggesting that the poor diodes have been removed from the population. Theses diodes that fail within 1000 hours are likely to have defects in the active region that act as non radiative recombination centers. For instance, the non radiative recombinations at the cleave surface generate heat that cause thermal runaway and eventually catastrophic failures.

Q4 b) Mean time to failure = 250,000hours.

i) The failure rate = 1/250,000 = 4×10^{-6} / hour.

$F(t) = 1 - \exp(-\lambda_0 t)$ where $\lambda_0 = 4 \times 10\text{-}^{6}$ / hour

After 1 year, $F(t) = 1 - \exp(-4 \times 10^{-6} \times (365 \times 24)) = 0.034$

ii) Probability of failure between 8 and 10 years

$F(8 \text{ years}) = 1 - \exp(-4 \times 10^{-6} \times 8 \times 365 \times 24)$

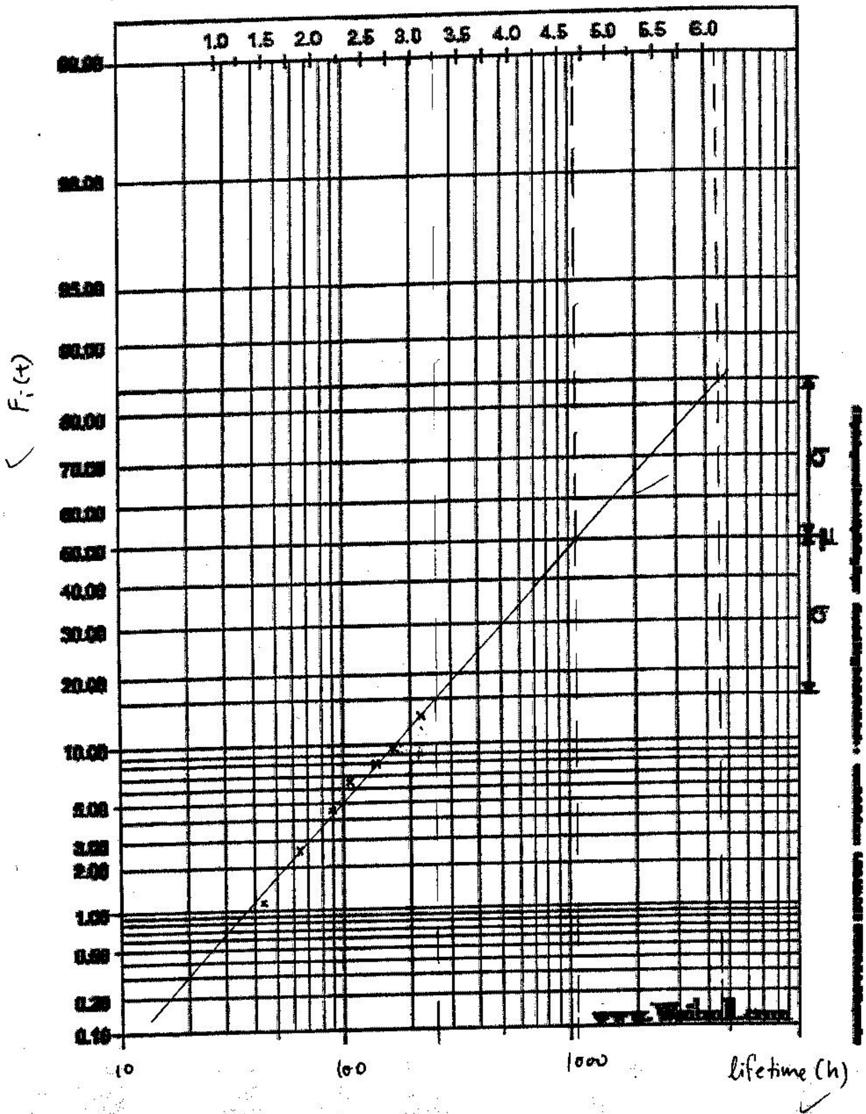
$= 0.244$

$F(10 \text{ years}) = 1 - \exp(-4 \times 10^{-6} \times 10 \times 365 \times 24)$

$= 0.296$

Probability of failure between 8 and 10 years = 0.296 – 0.244

= 0.05


1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0
99.99
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
0.20
0.10
$F_i(t)$
σ
μ
σ
www.Weibull.com
10
100
1000
lifetime (h)