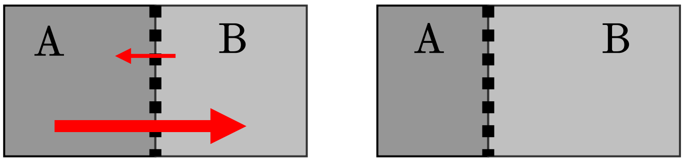
Self Assessment Questions (SAQs) 3

- Describe the Kirkdendall effect and discuss how it affects the reliability of an electronic device.

Consider a diffusion couple A and B, separated by an inert marker as shown below. If there is a net diffusion of atoms from A to B, the inert marker is effectively shifted to the left. This is the Kirkendall Effect.



This effect is important to reliability of electronic devices because of the presence of different types of metals in IC. For example Au ball is commonly used with Al bond pad in IC interconnects. Interdiffusion between AU and Al leads to Kirkendall voids that weaken the bond potentially leading to failure of the bond. Another example is the change in resistance due to interdiffusion between Cu and Sn in solder.

- What is electromigration? Is electromigration an important failure mechanism in IC? If so how can it be minimised?

Electromigration refers to migration of atoms along a conductor in the presence of high current density (10^5-10^7A/cm^2). The high current density, j_e, induce a force, $F = Z^*q\rho j_e$, which causes electromigration. Here Z^* is the effective charge number, q is the electron charge and ρ is the resistivity. Electromigration is an important reliability issue because current densities of 10^5-10^7A/cm^2 can occur in modern ICs where the conductor tracks can be < 1µm wide. Over a long period of time electromigration causes conductor degradation such as formation of hillocks and whiskers, void formation, thinning of metal, localised heating and cracking of passivating film.

Here are some methods to reduce electromigration.

- Short conductor can reduce electromigration because of the stress induced back-flow of atoms that counters the electron wind.
- Single crystal conductor with no grain boundaries is best to prevent electromigration.
- Bamboo structures can reduce electromigration significantly. Wide conductors have multigrain structures but when the ratio of thickness to width of conductors approach unity, mostly single grained or bamboo-grained structures are obtained.
- Grain boundaries oriented normal to current flow can also reduce electromigration.
- Films with more ordered structures, obtained using evaporated film have been suggested to be more immune to electromigration than sputtered films.
- Incorporation of Cu to form Al-Cu alloy increases the resistant to electromigration significantly. Cu rises the activation energy for Al migration. Use of multilayer with refractory metals such as Ti, W and TiN has a significant effect in reducing electromigration.

- Explain the origin of stress voiding and its relevance to reliability of electronic devices.

Voids arise from thermal stress due to the difference in the coefficient of thermal expansion between metal and relatively rigid dielectric (SiO_2 and Si_3N_4). The thermal stress leads to creation of grain boundaries and cracks that eventually become voids.
This is an important reliability issue in IC because Al conductors are often very narrow (<4μm) and are usually covered by dielectric which has very different coefficient of thermal expansion. Therefore stress voiding can lead to open circuit or increase in resistance of the conductors.

- What is Electrical Overstress (EOS)? What is Electrostatic Discharge (ESD)?

EOS refers to damage caused by excessive applied voltage, usually due to mishandling. Large current in ms to μs time scale causes failure of electrical/electronic component.
ESD refers to the transfer of charges from an object with higher potential to another object with lower potential until equal potential is achieved. ESD usually involves tens of kilovolts. Large current flows due to large voltage generated by static charges in ns time scale.

- Can you explain the potential reliability and failure issues caused by ESD and ways of minimizing ESD?

Failure examples are thin film burn-out, junction spiking and oxide breakdown. Sharp edges cause current crowding and high electric field. The high current melts the conductor while presence of high electric field increases the potential of dielectric breakdown. Degradation in the current-voltage characteristics is observed due to filament growth. Severe filamentation leads to junction spiking.
ESD induced high voltage cause charge injection into the oxide layer that leads to leaky junction. If high concentration of charge is injected, the effective thickness of the oxide layer reduces resulting in increasing electric field that cause oxide breakdown.

ESD can be minimised by

- Treat everything as static sensitive
- Touch grounded objects before handling electronic components
- Don't touch any leads, pins or tracks when handling devices.
- Minimise unnecessary movements
- Wear synthetic clothing (polyester, polypropylene or nylon) treated with antistatic finish.
- Wear grounding wrist strap (1MΩ resistor so that user does not become a low resistance path to ground).
- Store chips in conductive containers
- Place adequate protection networks at the input and at the power supply pins.
- Use grounded workstation. The surface should not induce any charge or provide discharge paths. ESD mat used.

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- Use grounded workstation. The surface should not induce any charge or provide discharge paths. ESD mat used.
- Control air humidity to 30-70% since ESD occurs more easily in hot and dry conditions.
- Inject conductive ions to neutralise objects and people entering a cleanroom. This is more effective than humidity control.
- Use conductive flooring with antistatic finishes. Choose footwear to match the floor.
- Wear heel ground strap worker needs to move.

- Outline how ESD effect can be simulated using equivalent circuit models.

ESD can be simulated using Human Body Model (HBM), Charge Device Model (CDM) and Machine Model (MM). In each of these models a capacitor is charged up to an intended voltage. This capacitor is then allowed to discharge via resistor and device, resistor and inductor in the HBM, CDM and MM respectively. The values of capacitor, resistor and inductor are important to obtain meaningful tests using these models. Referring to an example given in a previous lecture, we can calculate the current flow in the HBM using $i(t) = i_0 \exp(-t/\tau)$ where τ is the discharge circuit time constant and i_0 is the peak current given by $\frac{V_{HBM}}{R_B + R_{DUT}}$. The energy dissipated can be obtained from $E(R_{DUT}) = \frac{\frac{1}{2} C_B V_{HBM}^{\ 2} R_{DUT}}{R_B + R_{DUT}}$.

- Describe how hot carriers degrade performance of MOSFETs.

Hot carriers degrade performance of MOSFETs by injecting charges into the gate oxide. Some of the charges are trapped in the oxide. As these trapped charges increase with time they cause a shift in the threshold voltage and reduce the transistor gain. Hot carriers can be separated into
Drain avalanche hot carriers, channel hot electrons, substrate hot carriers and secondary generated hot carriers. Further descriptions of these hot carriers are given in lecture handouts.

- Describe the three types of corrosions that can occur in electronic devices.

Chemical, Electrochemical and Galvanic.

- Give examples of failures in IC due to corrosion.

Open circuit due to corrosion or short because of dendrite formation.
Sulphur dioxide (SO_2) produced by combustion of fossil fuel, forms corrosive sulphuric acid in the presence of moisture.
Carbon deposits such as soot, causes galvanic corrosion when in contact with most metal.

Chlorine ions originating from solvents, hydrochloric acid and chloride bearing fluxes, is another corrosive contaminant.
Al-Cu-Si a commonly used metallization scheme suffers loss of Al due to galvanic corrosion which take place during wet etching and use of chlorinated solvents.