GODDARD SPACE FLIGHT CENTER

Evaluation Report

Report Number EV72015
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Microcircuit (3)
MFR:Linear Technology
P/N: LT1014IS
D/C: 9617

Project
EEE Parts and Packaging

System
PEM

Requester
G.Rose (312)

Malfunction Report

Incoming Inspected

Initiated Date
10/21/96

Purchase Specification
Commercial

Screening Specification

Investigator
A. Teverovsky

Technical Approval/Date

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Approval for Distribution/Date

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Background

Three Linear Technology LT1014IS microcircuits (SNs 2, 8, 10) were received by the GSFC Parts Analysis Laboratory for dye penetrant testing and cross sectioning. It was requested that emphasis be placed on possible delaminations at the interfaces between the plastic package and the leads where ingress of chemicals (flux, Uralane, contamination) may have occurred.

These three parts had been pre-conditioned as follows. The parts had passed 5 cycles from -40°C to +60 °C, to simulate shipping conditions, and had been baked at +125 °C for 16 hours and soaked at +30°C/60 %RH for 24 hours to simulate floor lifetime. Next the parts had been subjected to infrared (IR) reflow soldering to boards (with maximum temperature of +260°C for approximately 20 seconds) followed by board coating with Uralane. Finally the parts had been desoldered, and the coating had been removed mechanically and chemically. The soldering/desoldering and conformal coating/coating removal process had been repeated to simulate one rework of the board.

Part Description

The Linear Technology LT1014IS is a quad, precision operational amplifier. It consists of two identical dice mounted to a die paddle using silver filled epoxy die attach material. Wire bond pads are interconnected with the package terminals using 1.5-mil gold wires which are thermosonically ball bonded at the die. Crescent bonding is used to connect the wires to silver plated (at the internal tips) copper leads. The part is encapsulated in a 16 lead, small outline (SOL) package with an epoxy novolac molding compound.

Analysis

External visual examination revealed remnants of flux and coating on the packages and gaps between the leads and molding compound (see Figure 1). As received, the parts showed evidence of soldering. Pins 8 and 16 had been cut off of each part.

All samples were subjected to dye penetrant testing per MIL-STD-883D, Method 1034. SNs 2 and 8 were cross sectioned along the leads (short axis) and SN 10 was cross sectioned perpendicular to the leads (long axis) at multiple planes as shown in Figures 2, 3, and 4. Before cross sectioning, and after sectioning to each individual plane, the parts were examined under ultraviolet (UV) illumination using a low power microscope (25X) and under bright field illumination using a high power microscope (up to 400X). Sections at planes 3 to 9 were also examined using a scanning electron microscope (SEM).

Before cross sectioning, during UV illumination, fluorescence was observed around most of the leads indicating multiple gaps. No cracks were found on the package surface. Further examinations showed that only sites near the leads, in the immediate vicinity of the package surface (up to approximately 300 -500 micrometers), fluoresced. This indicated that there were short gaps around the leads near the package surface. No fluorescence was observed at the paddle-to-compound, die-to-compound, or lead-to-compound interfaces inside the package (even at the sites where delaminations were found using SEM examinations).

SEM examinations revealed multiple sites of delamination between the top of the die paddle and molding compound. Locations of these sites are shown in Figures 2 - 4. Due to a small thickness (1 - 1.7 micrometers maximum), the delaminations were hardly visible during optical examinations under a high power microscope.

Figures 5 - 8 represent views of different sites where delaminations were observed. Note that delaminations were not continuous gaps, but were sporadically bridged with molding compound (e.g. see Figure 7). Delamination thickness at the edge of the die paddle decreased towards the bottom side (see Figure 9). No delaminations or cracks were observed at the bottom side of the die paddle or at the die-molding compound interfaces (see Figure 10).

Delamination between the top of the die paddle and molding compound propagated to the die adhesive area. At the die corners, the delamination switched from the adhesive-to-paddle interface to the adhesive-to-die interface, as shown in Figure 11.

Views of a crescent wire-to-lead bond and a ball bond-to-die cross section are shown in Figures 12 and 13. In both cases, no voids, cracks, or delaminations were observed. Molding compound was found to be in intimate contact with the wire, lead frame, and die, suggesting adequate mechanical robustness and corrosion resistance.

Discussion

Typically, "popcorning" in PEMs (resulting from a solder reflow process) manifests itself in delaminations which are located at the bottom of the die paddle - molding compound interface and in cracks which originate from the paddle edge and which can extend up to the package surface. No cracks or delaminations were found at the bottom of the paddle, suggesting that no popcorning effect had occurred.

Parts from the same lot, which had not been subjected to reflow simulation, were previously found to have fine (less than 0.5 micrometer) delaminations along the die paddle top-molding compound interfaces (see Report EV62563). The present results show that the reflow simulation had caused an increase in the delamination thickness at these interfaces (up to 1 - 1.7 micrometers) but that no delaminations had been developed at the other interfaces. In the LT1014IS design, silver is plated only on the lead tips used for wire bonding and on the top of the paddle. The rest of the copper lead frame remains silverfree. Since epoxy molding compounds adhere less well to noble metals (e.g., silver) than to copper, this explains why delaminations only occur at the top of the paddle. The gaps around the leads, which initiated from the package surfaces, did not extend more than 300 - 500 micrometers along the leads and did not form through-paths for moisture and contamination ingress towards the die surface.

In the earlier study (EV62563), silver epoxy die attach was found to delaminate from the gold plated die bottom. This study showed that the solder reflow simulation did not affect the die attach-paddle interface but, instead, slightly increased the delamination at the die side of the adhesive (which most likely existed previously). One reason that the delamination occurred at this location is that adhesion to silver may be better than to gold. Another, and more probable, reason is a poorer adhesion strength to the die due to organic contamination which can remain on the wafer backside from tape which is used during the dicing operation.

Delaminations in plastic parts, especially after solder reflow processes, are common but the question of how these will affect long term reliability has not yet been fully investigated. No official document describes rejection criteria for delaminations in PEMs. Some analysis has shown that, most likely, only delaminations which are located at wire bond sites, or, those which are located at the die-molding compound interfaces, are of reliability concern.

Other studies show that parts with delaminations remain stable following the assembly process, suggesting that further delaminations probably will not develop.

Exposure of parts with delaminations to moisture environments may result in water condensation in the gaps. However, calculations show (see Appendix) that, for a package of 2 mm thickness, the time required to fill up a 1 micrometer gap is approximately 2×10^6 hours, which is approximately three orders of magnitude more than the time required for moisture to penetrate to the die surface (at room temperature). Even if condensation occurs at the paddle-molding compound interface, it likely would not result in failure. The only conceivable mechanism of failure is popcorning when the part would be subjected to reflow after water had accumulated in the delamination. This is considered to be very unlikely to occur provided that proper precautions are taken to prevent popcorning.

Delaminations at die-adhesive interfaces have been shown to affect thermal resistances only for PEMs with power ratings greater than 1 watt. As a result, the delaminations observed in the LT1014IS microcircuits will likely not affect the thermal resistances.

Cross sectioning revealed multiple sites of glassivation cracks (see Figure 14). No glassivation defects were observed during the glassivation integrity examinations in another previous study (EV61261). When parts from the same lot were cross sectioned, single glassivation defects were observed (EV62563). These single defects probably were due to the grinding process itself. Defects found during this evaluation were suspected to have been caused by the reflow process rather than to have resulted from sectioning. Since glassivation cracks make devices more vulnerable to failure, additional experiments are suggested to more completely investigate solder reflow effects on glassivation integrity.

Conclusions

Die penetrant testing of the three submitted Linear Technology LT1014IS microcircuits, after solder reflow simulation, revealed short gaps around the leads. The gaps did not extend more than 300 - 500 micrometers from the package surface and it is considered unlikely that these would result in chemical ingress towards the die or wire bonds.

Cross sectioning and SEM examination revealed delaminations (up to 1 - 1.7 micrometers in thickness) between the top sides of the paddles and molding compound. These also revealed delaminations (less than 1 micrometer) at the die-adhesive interfaces. No cracks or delaminations at the other interfaces (die-to-compound, bottom side of the paddle-to-compound, or internal parts of the leads-to-compound) were observed. Comparing these results with those from a previous analysis (EV62563) shows that the reflow process likely worsens any delaminations which may pre-exist at the paddle top interface. However, these small delaminations are not considered to be a reliability concern.

SEM examinations revealed cracks in the die glassivation which were conjectured to be caused by the reflow process. Additional studies would be necessary to investigate their origin and effect on reliability of the parts.

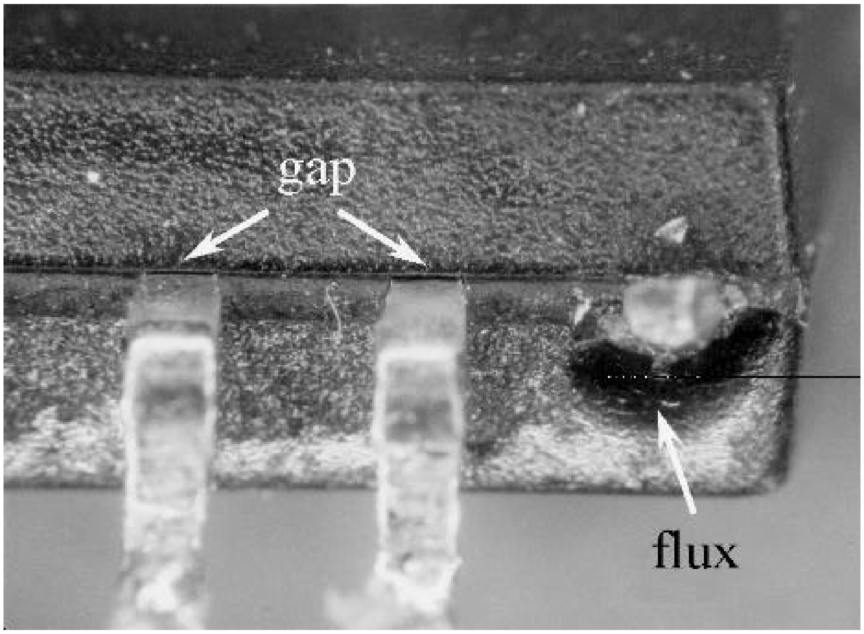


Figure 1. An optical view of the LT1014IS microcircuit showing gaps between the leads and molding compound, SN 10. (25X)

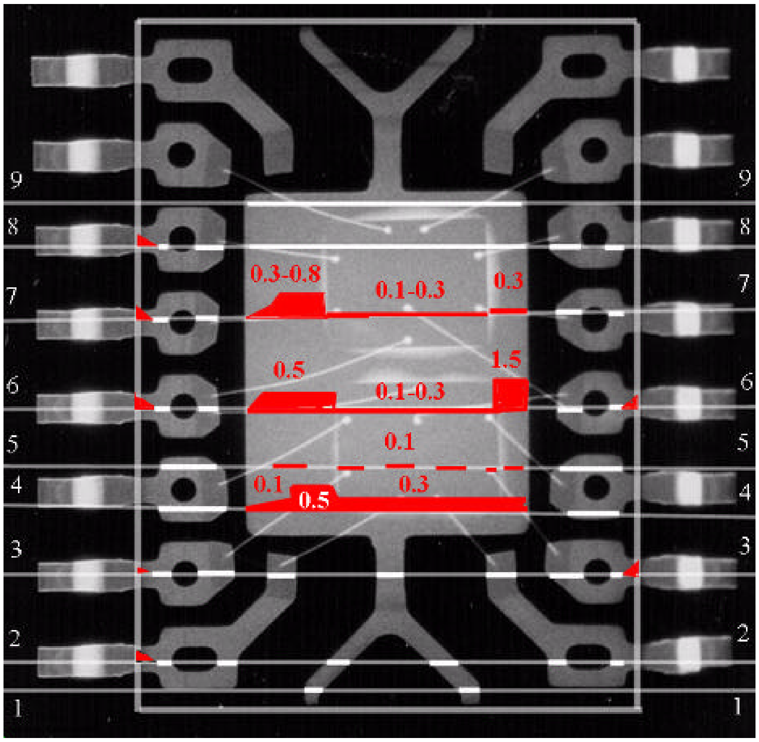


Figure 2. Locations of a cross sectional planes and areas of observed delamination, SN 2. Red color and figures denote delamination and its thickness in micrometers. White color denotes that no delamination has been observed.

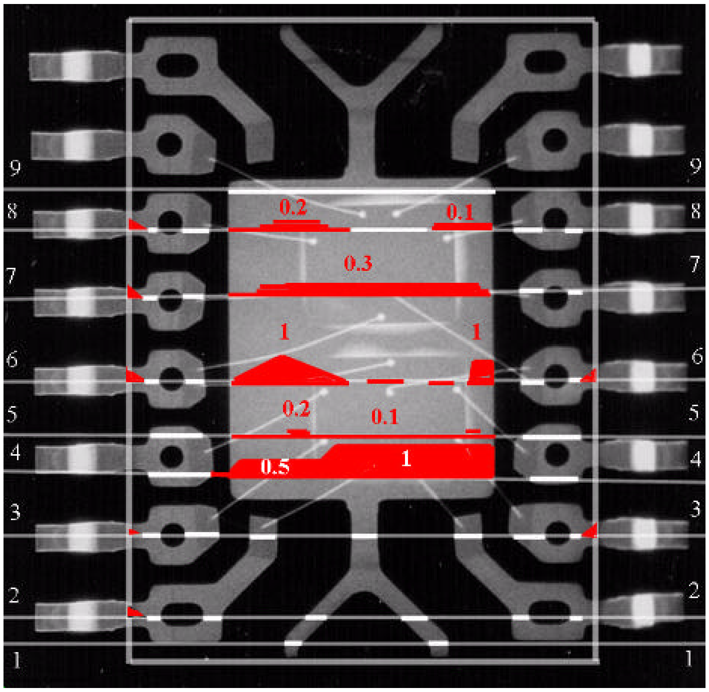


Figure 3. Locations of cross sectional planes and areas of observed delamination, SN 8. Red color and figures denote delamination and its thickness in micrometers. White color denotes that no delamination has been observed.

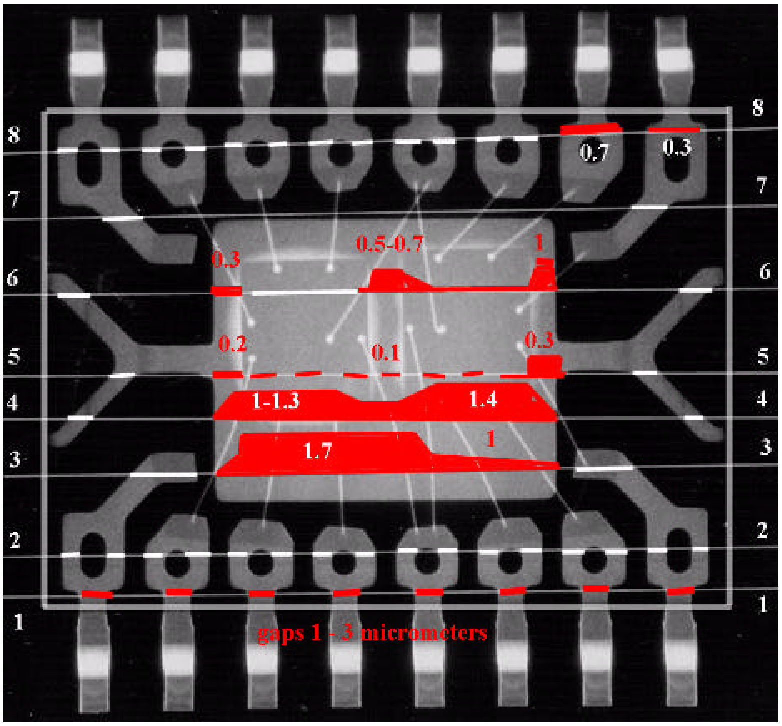


Figure 4. Locations of cross sectional planes and areas of observed delamination, SN 10. Red color and figures denote delamination and its thickness in micrometers. White color denotes that no delamination has been observed.

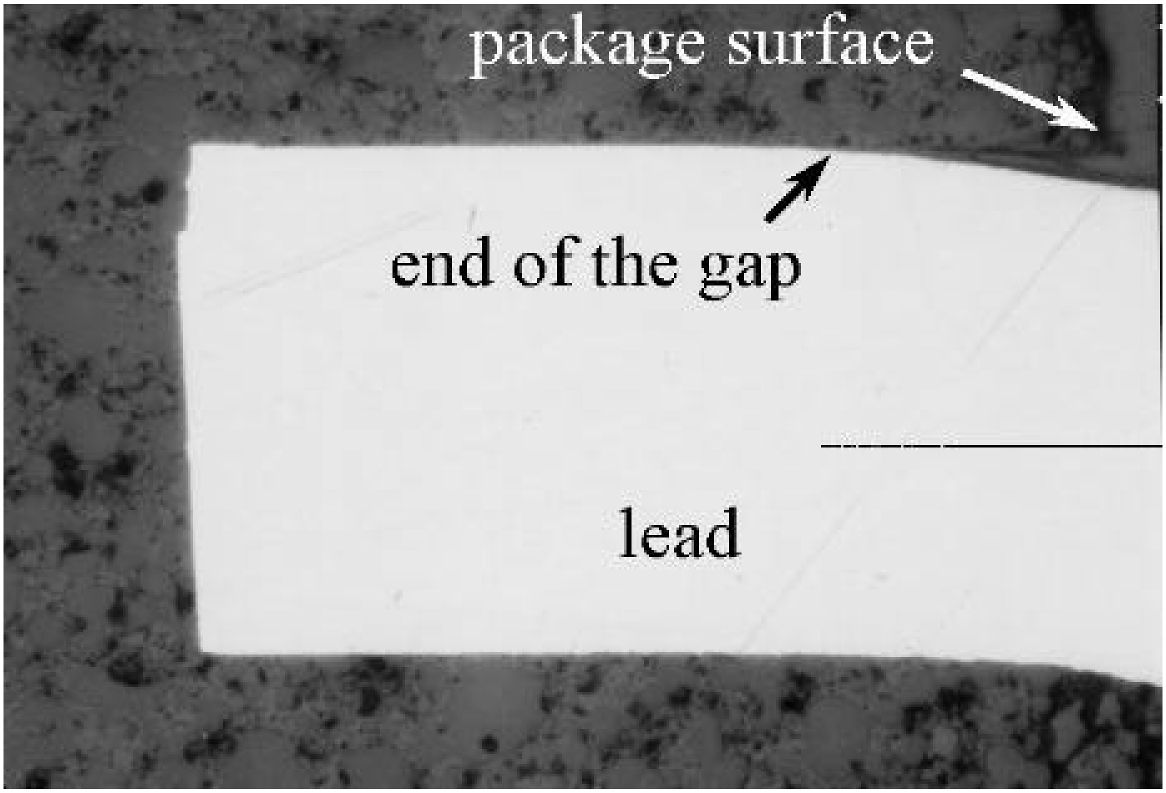


Figure 5. Optical cross sectional view of a lead, SN 8. (200X)

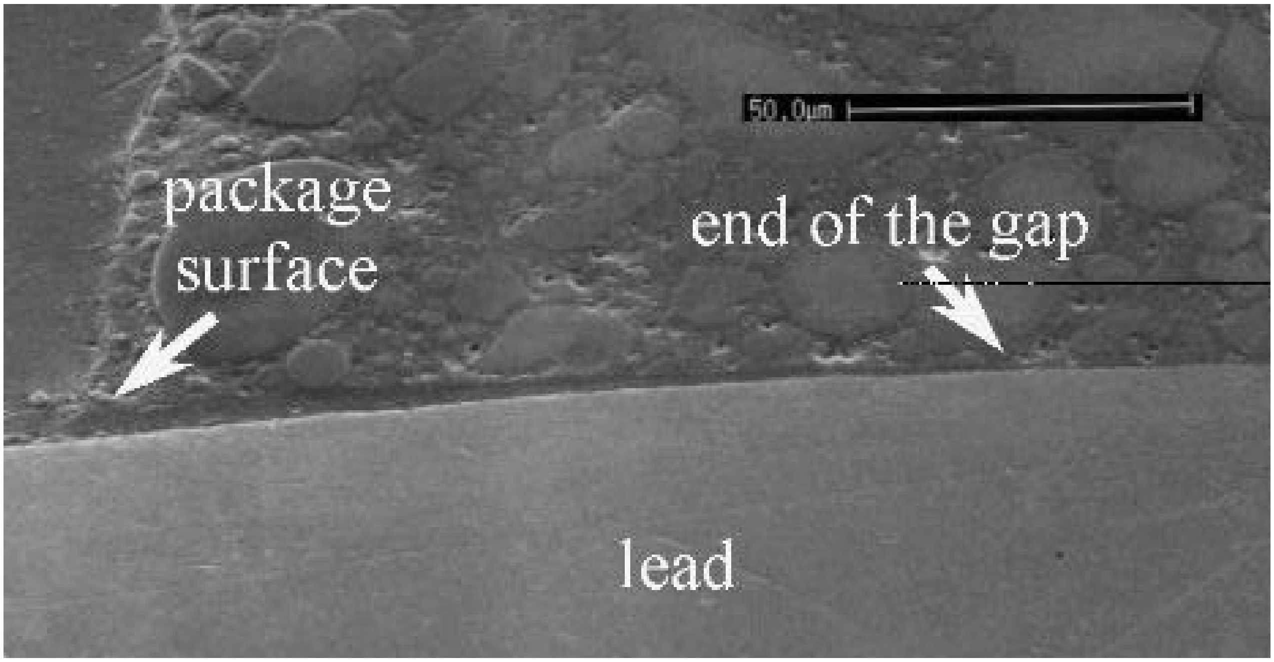


Figure 6. SEM cross sectional view of another lead, SN 8. (615X)

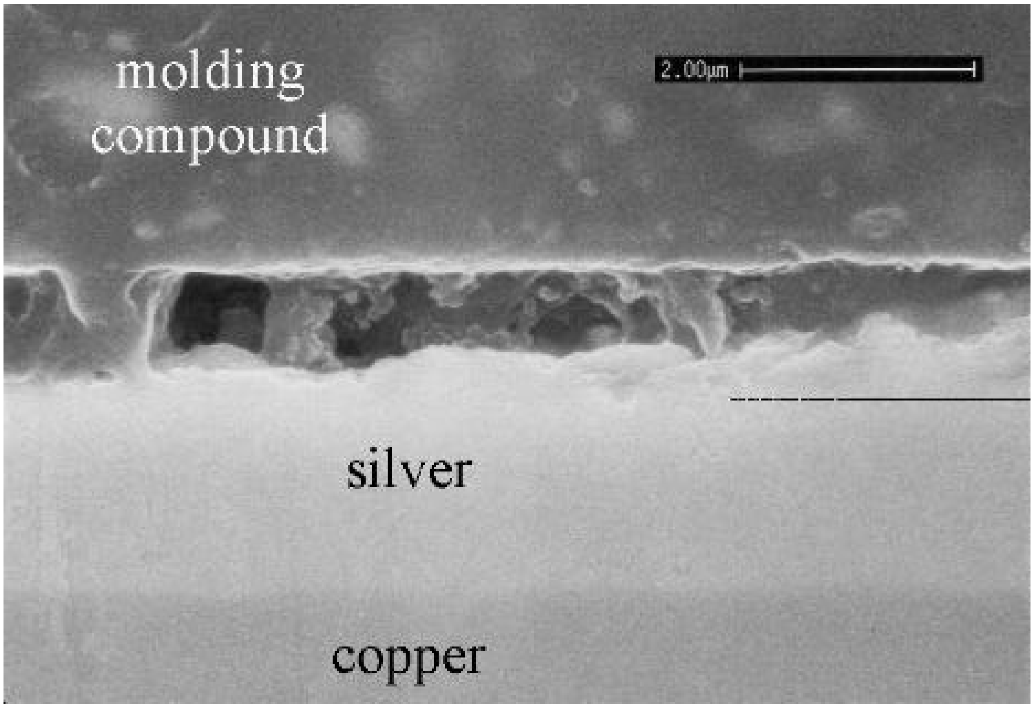


Figure 7. Delamination between the die paddle and molding compound at plane 4, SN8. (12900X)

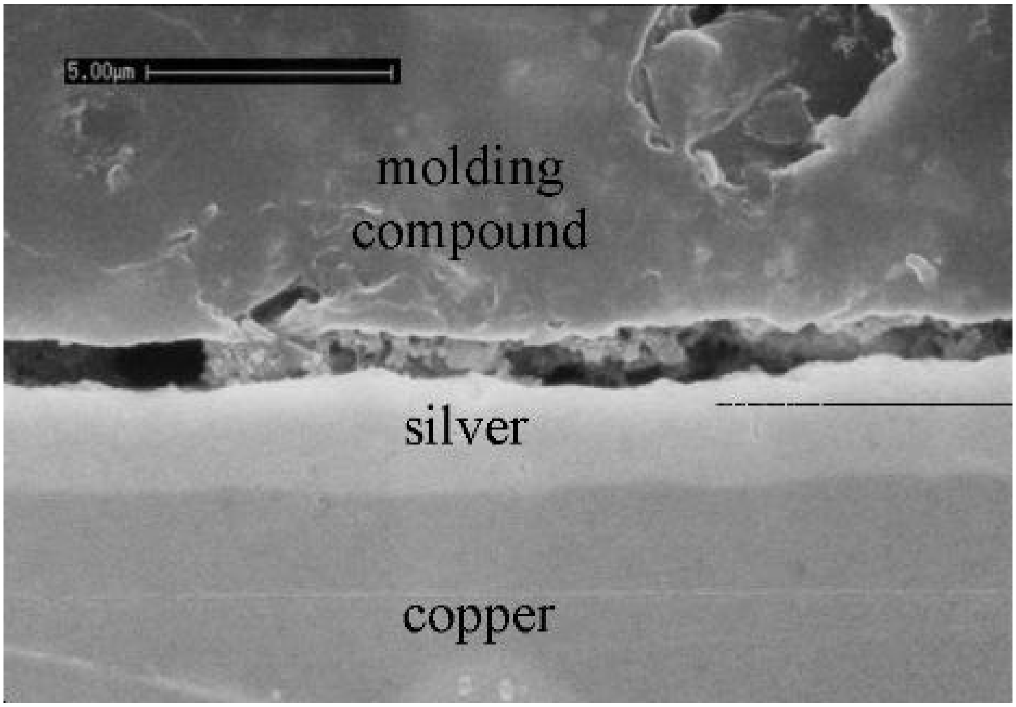
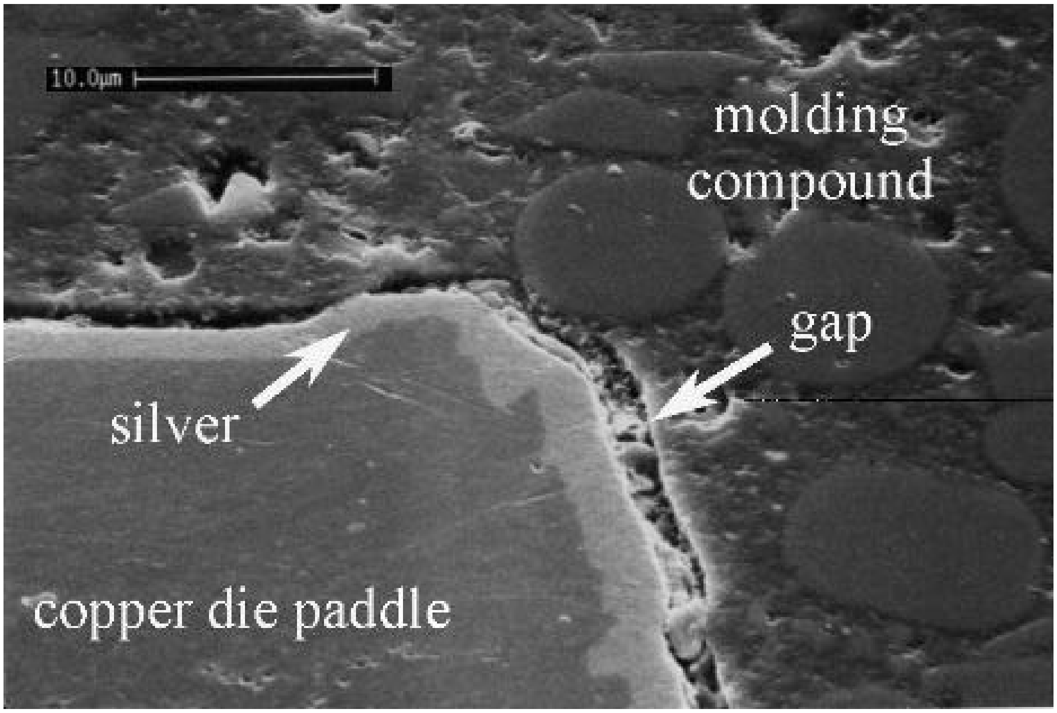
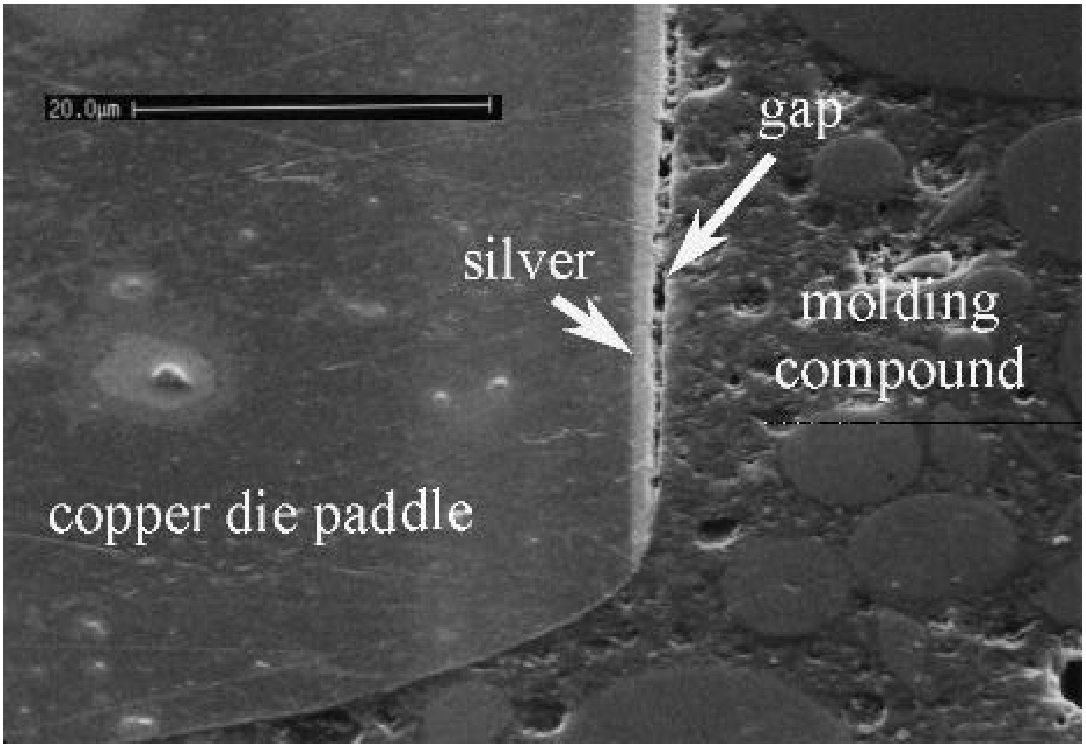


Figure 8. Another view of the die paddle-to-molding compound delamination, plane 4, SN10. (5500X)



a) (2600X)



b) (1880X)

Figure 9. Delamination at the top (a) and bottom (b) of the die paddle edge, plane 6, SN 10. (794X)

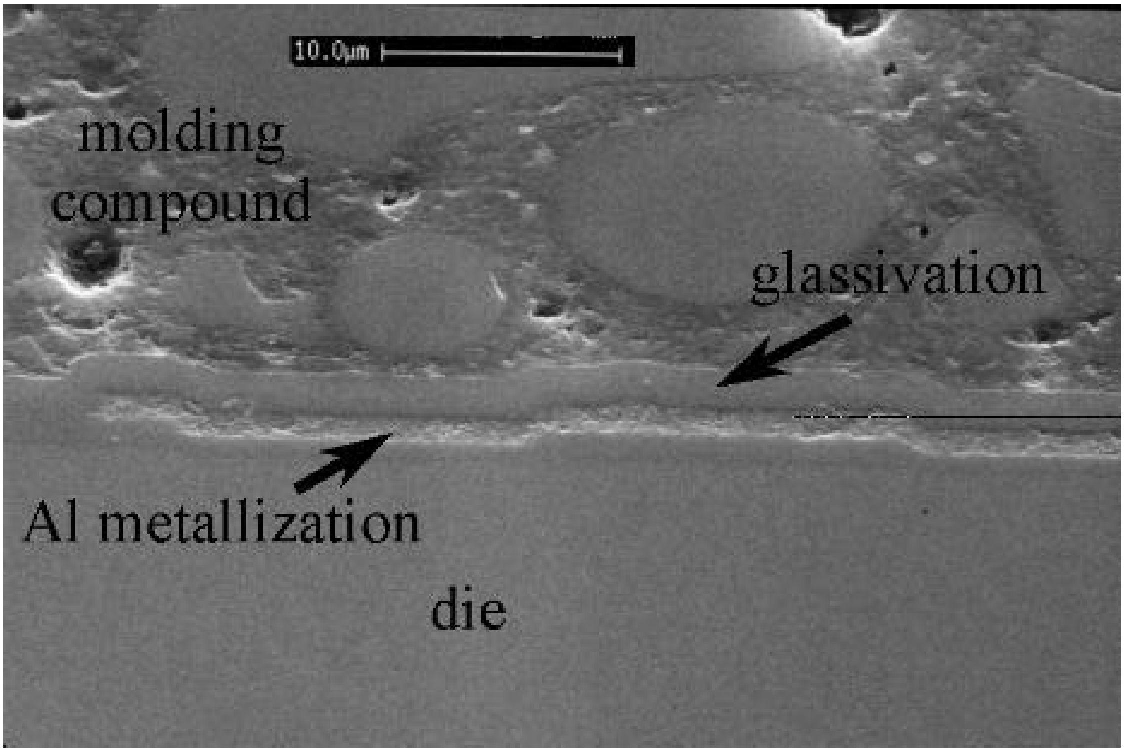
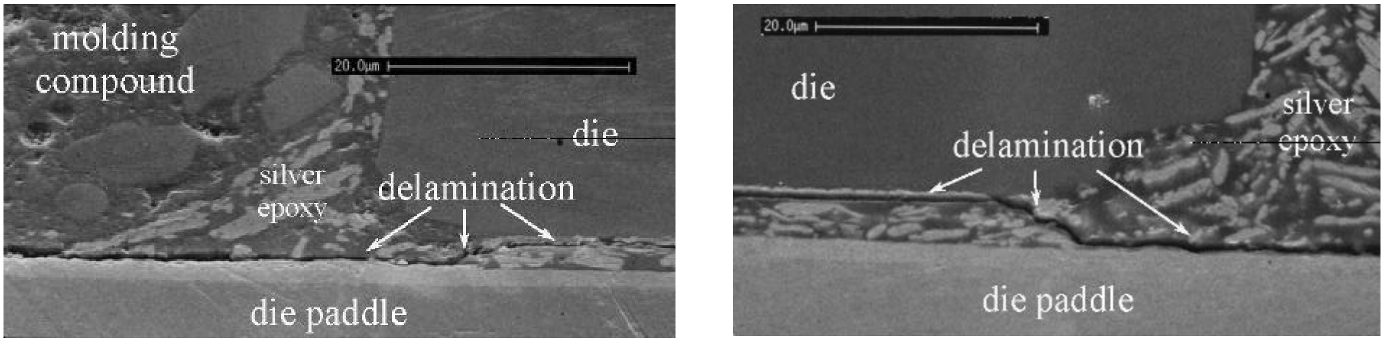


Figure 10. Die-molding compound interface, plane 5, SN 8. (2430X)



a) SN 2, right edge of the die, plane 6 (2000X)

b) SN 8, plane 7, left edge of the die, (1920X)

Figure 11. Crack propagation under the die.

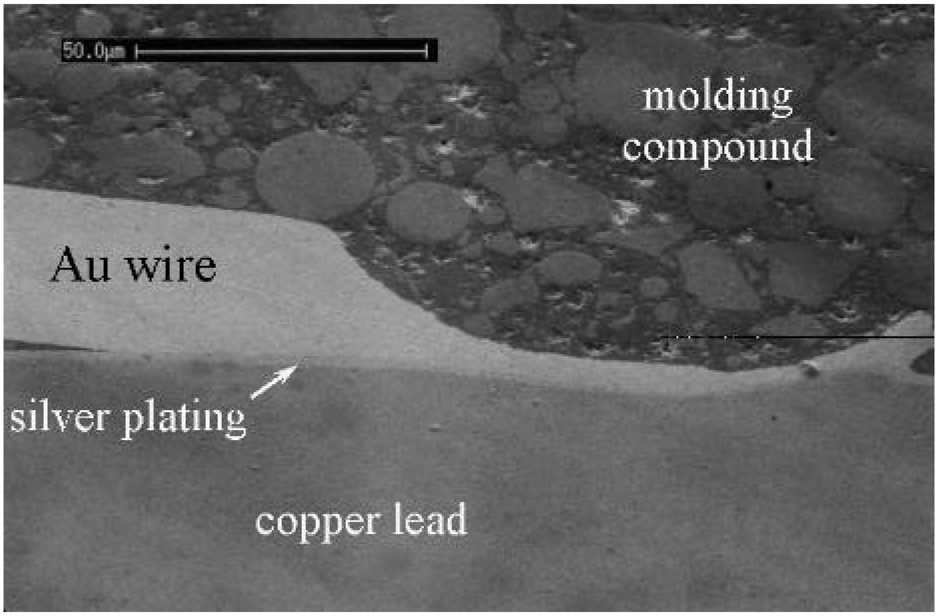


Figure 12. A SEM view of the crescent bonding, plane 6, SN 8. (708X)

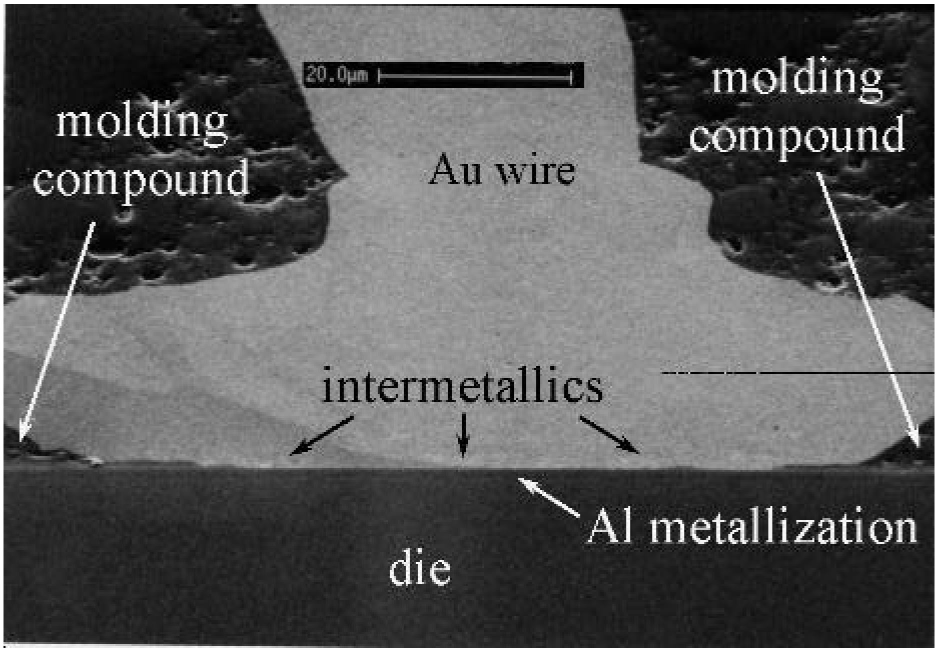
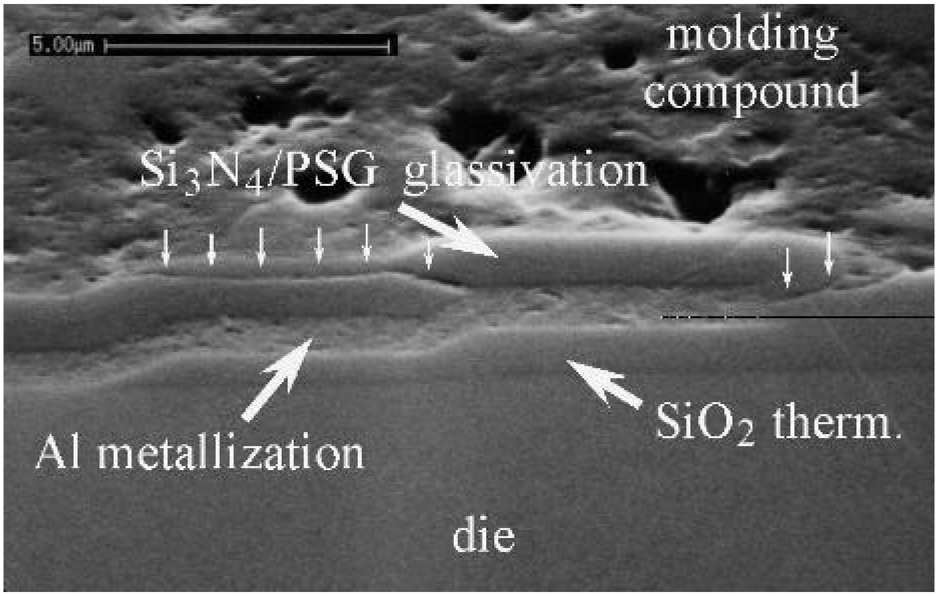
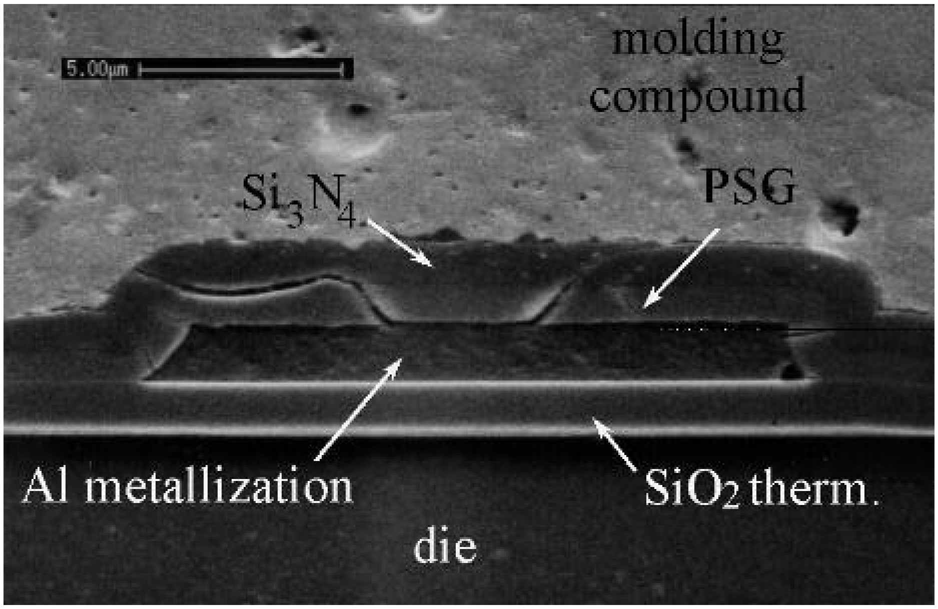


Figure 13. A SEM view of the ball bonding, plane 7, SN 8. (1170X)



a) SN 8, plane 7. Fine arrows indicate cracks (6940X)



b) SN 2, plane 7 after dash etch (4930X)

Figure 14. Glassivation defects.

Appendix

Capillary Condensation of Moisture into a Gap.

The process of moisture condensation into a gap between the die paddle surface and molding compound is represented in Figure 1. For simplicity, it may be assumed that this process starts after a steady moisture concentration over the package has been established.

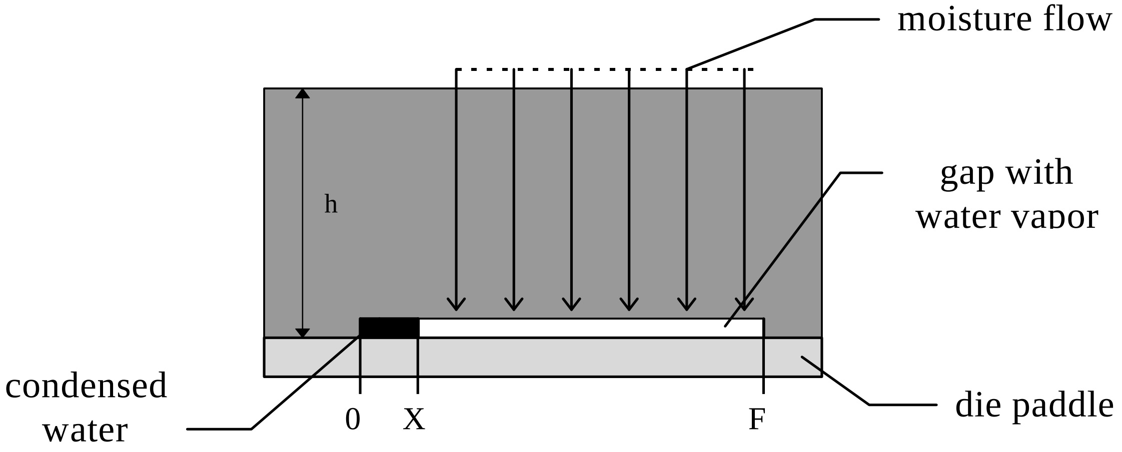


Figure 1. Process of moisture condensation in a gap in plastic package (only one-ha
of package is shown).

Moisture diffusion flow into the gap during time (dt) would result in an increase of the moisture mass dm according to equation:

$$dm = \frac{D\times \quad \times(P_o - P_r)\times(F-X)}{h}\times dt \qquad (1)$$

where σ is the solution coefficient of moisture in the molding compound;
D is the coefficient of moisture diffusion;
F is the width of the gap;
X is the width of the area in which water vapor has condensed;
P_o and P_r are partial moisture pressures outside the package and inside the gap;
h is the thickness of the molding compound from the die paddle to the package top.

In the gap, moisture mass dm is condensing thus increasing the width of water layer (dX):

$$dm = r\times \quad \times dX \qquad (2)$$

where ρ is the specific density of water;
r is the thickness of the gap.

Appendix (con't)

Equating expressions (1) and (2) yields the following differential equation:

$$\frac{dt}{\quad} = \frac{dX}{(F - X)} \qquad (3)$$

where $= \dfrac{h \times r \times}{D \times \quad \times (P_o - P_r)}$ is the characteristic time required for water condensation.

The solution to Eq. (3) is a simple exponential function:

$$X = F \times [1 - \exp(-t / \quad)] \qquad (4)$$

After time t = 3 , the condensation process will practically be completed (95% of the gap will be filled with water).

Due to a capillary phenomenon, the moisture pressure in the gap, P_r, will be less than the ambient moisture pressure, P_o. Their ratio will depend on gap thickness, r, according to the Thomson equation:

$$RT \times \ln(P_o / P_r) = \quad / r \qquad (5)$$

where γ is the surface tension of water (7.3×10^{-2} N/m),
ν is the molar water volume (1.8×10^{-5} m^3);
R is the gas constant (8.3 Nm/mole K).

Results of pressure calculations for different gap thicknesses are given in Table 1.

Table 1. Capillary Pressure and Characteristic Time
of Moisture Condensation for Varying Gap Thicknesses. (Assumes h=1mm).

r, μm	P_o/P_r	Pr, Pa	, hr
0.01	1.0542	2162.8	237
0.03	1.0177	2240.2	2,096
0.1	1.0053	2268.0	23,147
0.3	1.0018	2275.9	207,965
1	1.0005	2278.8	2,309,305
3	1.0002	2279.6	20,780,086

Appendix (con't)

The characteristic times of water condensation for a package with a total molding compound thickness of 2 mm (h = 1 mm) at room temperature are also shown in Table 1. A typical epoxy compound, with a diffusion coefficient $D = 1\times10^{-13}$ m^2/s and a solution coefficient $\sigma = 1\times10^{-3}$ m^2/sec^2 , was assumed for these calculations.

It can be seen that any substantial difference in the moisture pressure inside and outside the gap (mor than approximately 0.1%) occurs only for very small gaps (those with thicknesses less than 1 micrometer). For a gap 1 micrometer in thickness, this difference is only 0.05%. The characteristic time for water condensation rapidly increases with gap thickness and exceeds the characteristic time for moisture diffusion stabilization for gaps more than 0.01 µm thick. One reason for this is that the "driving force" of the condensation process (difference in moisture pressures outside the package and inside the gap) is lower than the "driving force" for moisture diffusion into an initially dry package (difference in moisture concentrations at the outer surface of the package and at the die surface). Another reason is the fact that the density of water vapor is approximately 100,000 times less than that of water. This means that many more water molecules have to penetrate the gap to fill it with water than to fill it with water vapor.