Moisture-Sensitivity Classification of Flange-Mounted Packages at Texas Instruments

Application Report

Literature Number: SLZA002
September 2007

TEXAS INSTRUMENTS

Contents

List of Figures

Moisture-Sensitivity Classification of Flange-Mounted Packages at Texas Instruments

Edgar R. Zuniga *HVAL Packaging*
Lance Wright

1 Introduction

Moisture-sensitivity testing (MSL) of flange-mounted packages is performed using the Joint Industry Standard IPC/J-STD-020C guidelines for surface mount technology (SMT) packages.

Although the same testing methodology is required for all standard SMT packages like SOP, QFP or TSOP; flange-mounted and SMT packages with exposed die paddle (see Figure 1), require additional testing to properly assess the MSL performance of the package and its reliability for lead-free processing.

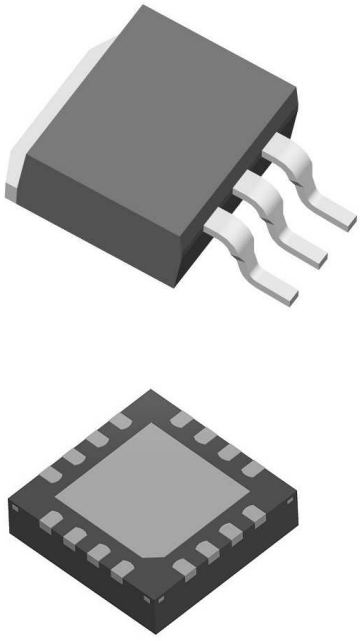

Figure 1. Flange-Mounted Packages and Packages With Exposed Die Paddle

This application report explains the methodologies that can be used to assess and improve the robustness of flange-mounted and SMT packages with exposed die paddle and down bonds.

2 Problem Statement

Flange-mounted packages or packages with the die paddle exposed are more prone to die paddle delamination primarily because of the unbalanced encapsulation of the package as shown in Figure 2.

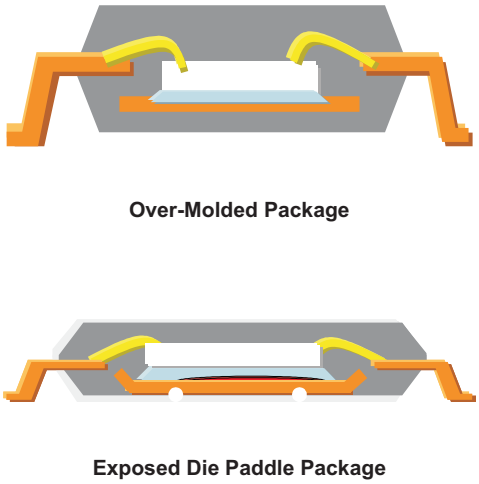

Figure 2. Construction Differences Between an Over-Molded and SMT Package With Exposed Die Paddle

The unbalanced construction of flange-mounted packages creates an increase in the mechanical stresses at the die to die-paddle interface during IR reflow. This leads to an increase in die paddle delamination.

The degree of die paddle delamination also is affected by other factors like die-paddle to die-size ratio, leadframe finish, material selection, and assembly process variations (bond line thickness, curing profile, fillet height, etc). The relationship between some of these factors to the degree of delamination is shown in Figure 3.

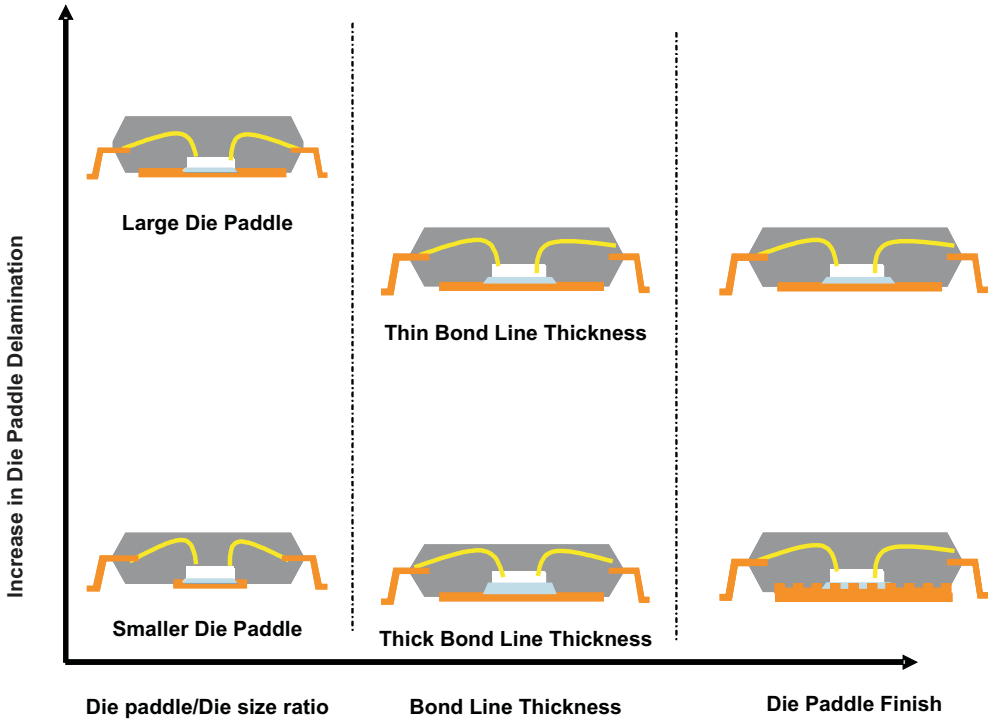

Figure 3. Factors Affecting Die Paddle Delamination

Delamination between the die paddle and the mold compound may not be a major problem unless the delamination intersects the location of downbonds located on the die paddle.

Die paddle delamination between the backside of the die and the paddle itself may or may not be a problem depending on the thermal requirements of the device. Because flange-mounted packages or packages with exposed pad are primarily used on devices requiring good heat dissipation, delamination at this interface area could be a major reliability problem, in some instances causing the device to shut off due to overheating.

This document addresses only the issues related with delamination between the mold compound and the die paddle in conjunction with down bonded wires. The reliability issues related to delamination between the backside of the die and the die paddle is not discussed on this dcoument, although the problem has been the subject of extensive work done at Texas Instruments.

When delamination between the mold compound and the die paddle is present, the mold compound is free to move in relation to the die paddle during temperature cycle excursions. Because of the differences in coefficient of thermal expansion between the die paddle, the silicon die, and the mold compound, the movement of the mold compound could cause the wires to break at the die paddle-wire interconnection interface as shown in Figure 4. Figure 5 shows a typical wire breakage failure mode during IR reflow or after temperature cycle if delamination is present.

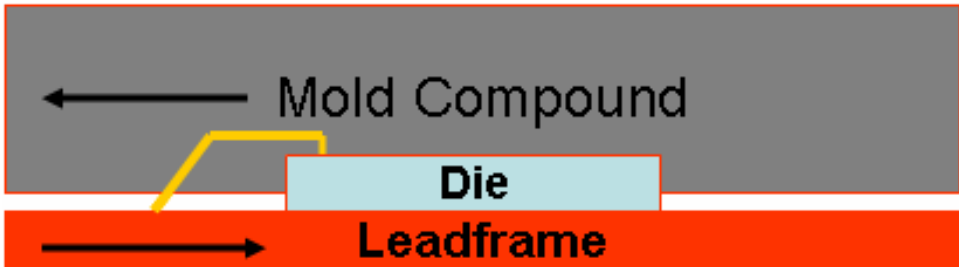

Figure 4. Cross Section Showing Mold Compound to Die Pad Delamination

The broken wire bonds depicted on Figure 5 were found after subjecting packages to the JEDEC 020 specification followed by 1000 temperature cycles (–65 to 150°C) as specified by JESD22-A104-B.

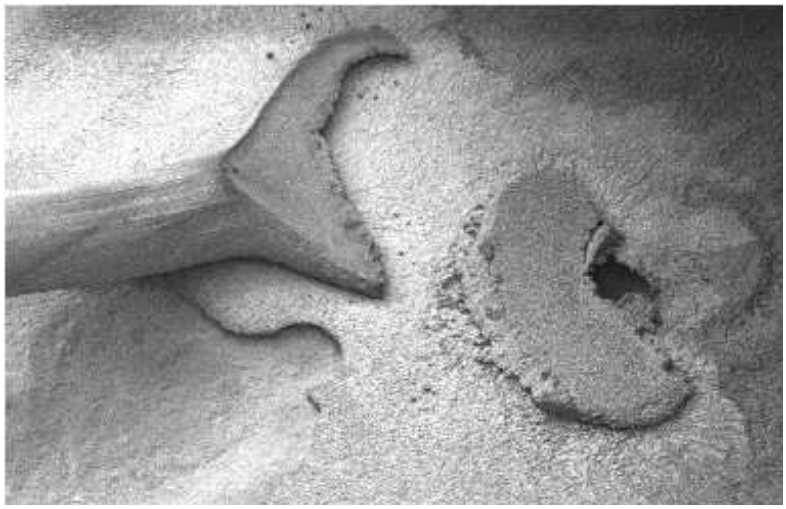

Figure 5. Typical Failure Mode of Down-Bond Wires Located on Die Paddle Delamination Areas

The presence of delamination may or may not cause the wire bond to break (wire stitch location is also a factor). The delamination may not even cause the device to fail even if the wire is broken. Although the bond wire may no longer be “hard” connected to the die paddle, the device may still pass electrical testing. This is because the wire may still be in electrical contact to the die paddle as a result of the pressure exerted by the mold compound.

This condition may lead to errors when judging the MSL test results. The implications could result in the release of a package with marginal MSL performance.

3 Moisture Sensitivity Testing of Flange-Mounted Packages

Moisture-sensitivity testing level (MSL) of flange-mounted packages is determined by following the procedures outlined in the joint Industry Standard IPC/J-STD-020C. The procedure basically consists of the following[1]:

- **Initial electrical testing per device datasheet values**. Objective is to make sure only good devices are subjected to MSL testing.
- **Initial Inspection**. This is to establish a baseline for cracking and delamination at time zero (before submitting the units to the actual test).
- **Bake**. Samples are baked for 24 hours at 125 +5/-0 °C. The intention is to remove moisture from the packages under test.
- **Moisture Soak**. Units are submitted to the appropriate soak-time requirements per intended MSL expected performance.
- **Reflow**. Within J-020C specified time units are submitted to reflow.
- **Final External Visual Inspection**. Looking primarily for cracks in the package.
- **Final Acoustic Microscopy (CSAM)**. This is to determine level of delamination.

Note: Level of delamination is estimated based on the amount of “red” color seen on the scanning acoustic microscopy (SAM). Areas with no red color are believed to have no delamination.

Per J-STD-020C, to evaluate the impact of delamination on device reliability, the semiconductor manufacturer shall either meet the delamination change requirements shown in section 6.2.1.1 of J-STD-020C or perform a reliability assessment per appropriate qualification specifications. The reliability assessment may consist of stress testing, historical generic data analysis, etc. Texas Instruments uses the Jedec standard as a baseline but goes a step further as defined below:

1. Regarding the active side of the silicon, this delamination can be considered acceptable if results from the following tests are acceptable.
   a. A sample size of 77 units from 1 assembly lot preconditioned to the same MSL which showed the delamination as above must be stressed to 1000 cycles at the temperature cycle range for that package (–65°C/150°C, or –55°C/125°C, or –40°C/125°C). All units must pass functional testing and any fails must be analyzed to root cause and must not be related to the delamination.
   b. Another sample of 77 units from 1 assembly lot preconditioned to the same MSL which showed the delamination as above must be stressed to 96 hours of autoclave or 96 hours of unbiased HAST at 130C/85%RH or 264 hours unbiased HAST at 110°C/85%RH. All units must pass functional testing and any fails must be analyzed to root cause and must not be related to the delamination.
   c. After both tests above, take a sample of five stressed units that passed functional test, do a SAM analysis on them to measure the delamination area, and then decap them to reveal the bondpads. The method of decapsulation should be determined by the FA lab based on package materials and best known methods to inspect ball bond intermetallics. Any bonds that lift off from these samples in the delamination areas are considered a failure. Bonds lifting off due to non-delamination issues (intermetallic degradation, corrosion, etc) can be discounted with regard to this MSL determination. These non-delamination fails still need to be addressed as far as the package reliability is concerned. If delamination is seen crossing a bond wire, it is considered a failure against the quality specification.

2. For peripheral die pad delamamination, TI allows this type of delamination, but does additional investigations if the device has a down bond. To evaluate the integrity of the down bond, post 1000 cycle temperature cycle units are decapped and the stitch bond inspected. Any broken stitch bonds or cracks in the stitch bond are considered failures against the quality specification. In some cases, an additional 1000 cycles of temperature cycles are run to further evaluate the robustness of the stitch bond. Ways to improve stitch bond performance in the face of delamination are discussed in later sections of this document.
3. Delamination under the die is also another key area of concern for exposed pad packages as this can affect the thermal performance of the die. TI goes beyond looking at the die attach after MSL testing and does TSAM analysis after 500 cycles of thermal shock testing to ensure die attach integrity.

3.1 Delamination Mitigation Techniques

Delamination is a function of the package materials and the reflow stresses. The semiconductor manufacturer cannot control the latter but must focus on selecting new material to eliminate delamination or implement mitigation techniques to provide sufficient reliability for the application in the presence of delamination.

There are several mitigation techniques to improve the reliability or delamination performance without having to change the materials. Some of the techniques can be used individually or combined together and consist of ways to improve mold compound adhesion to the die pad, eliminate top-side die delamination, or improve the strength of the stitch bond.

The options to improve the stitch strength are ball-on-stitch security bump (BSB), stud stitch bond (SSB), and reverse stand-off stitch bond (RSSB), which are shown in Figure 6. TI has tested each option and found each to be more robust than the standard stitch bond. Additionally, all of these options are compatible with today's automated gold wire bonders and add minimal cost.

Options to improve mold compound adhesion, to lower the stress on the stitch, are selective plating on the die pad, adding a ground ring to improve mold locking around the stitch, adding mechanical mold locking features on the die pad such as grooves or dimples, bonding the stitch to a raised feature such as a tie bar, or using a simpler approach and increasing the MSL level (2→3, etc). Most of these techniques can be implemented with minimal costs.

There are not many options to eliminate top-side die delamination. A careful selection of materials (mold compound/die attach/leadframe finish) to provide balanced stresses between top and bottom of die is the best approach to avoid top-sde die delamination. One method that has been successful is plasma cleaning. Argon and Oxygen plasma cleaning are probably the two most common gases used in the industry today. Plasma cleaning helps make the surface more active and promotes better adhesion to the mold compound. Plasma cleaning has also been shown to improve mold compound to die pad or leadfinger adhesion. Another method is to increase the topology of the silicon through a different wafer fabrication process. These two methods are not as cost effective as additional assembly processes are required.

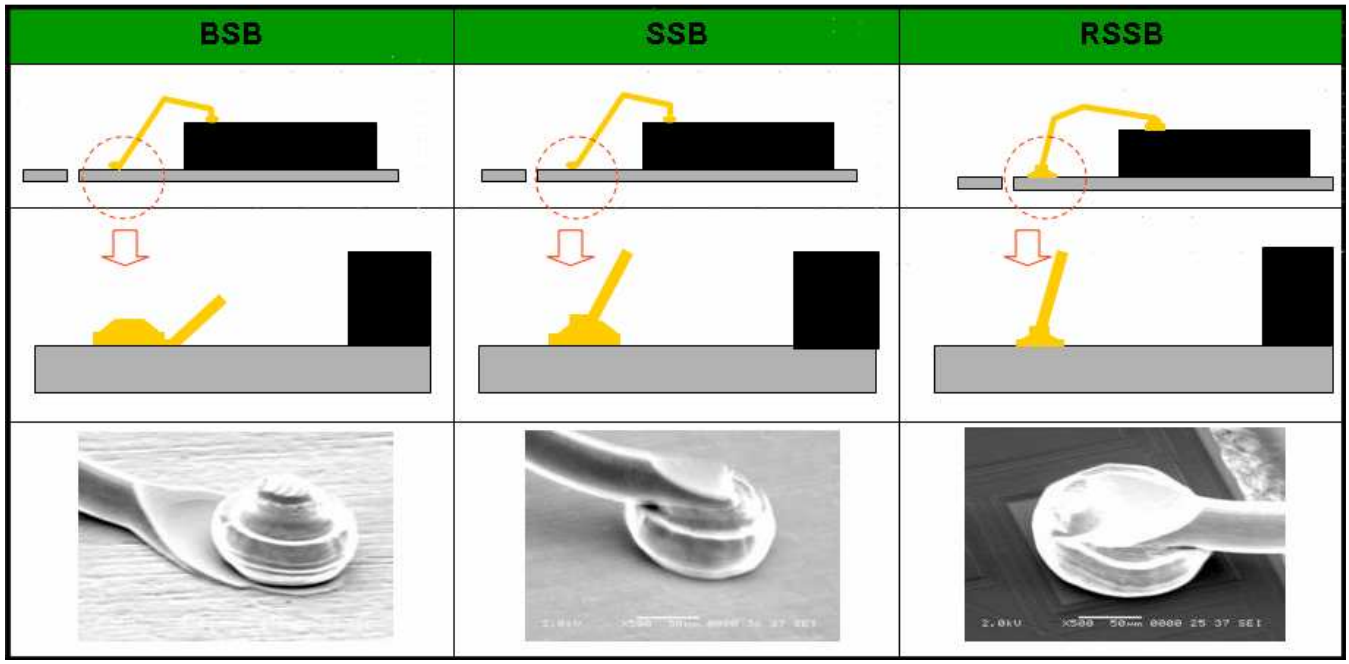

Figure 6. Stitch-Bond Options

3.2 Competitive Analysis

Flange-mounted packages like the TO263, TO252, SOT223 packages, due to its unbalanced construction, are very sensitive to moisture ingression, and delamination around the die is very typical. One key factor is that the die is usually small compared to the die paddle. During the TI development cycle of the TO263 package (TI code KTT), three qualification attempts failed due to broken standard stitch bonds on the down bond wires before a new material set was chosen and several mitigation techniques employed. TI now has a very robust TO263 package that has exceeded all test requirements. Due to the difficultly in achieving a Pb-free solution that passed all qualification requirements, TI investigated the performance of competitor MSL to gauge the range of delamination/package robustness in the industry on several different types of flange mount packages. The results from the analysis study are shown in Figure 7 – Figure 9.

The data shows a range of 100% delamination to zero delamination with the TI devices having the lowest levels of delamination. It should be noted that on the TO-263 and TO-252 packages, the TI devices are rated at MSL 3 whereas the other devices have a more aggressive MSL rating. Lower MSL levels tend to show more delamination but in some cases, the delamination performance can be the same at all MSL levels. TI's internal testing has shown that increased levels of delamination have an impact on long term reliability. Another observation is that some IC suppliers allow for top-side die delamination that is not present on the TI devices. Issues with top-side die delamination and component reliability are well documented in the industry and need not be repeated here. It is best not to have this type of delamination. When focusing on the areas around the die, the TI devices have zero or partial delamination whereas all the other supplier devices have 100% delamination. In the case of SOT-223, the MSL rating is the same. As previously discussed, this type of delamination can affect down bond robustness. This is why it is recommended to decap after the appropriate stress tests to validate the integrity of the stitch bond. Additionally, electrical testing does not always capture fractured stitch bonds. This has been proven in TI's failed qualification. It takes longer than the standard testing cycles to show a complete "open." None of the analyzed devices were submitted for reliability testing due to insufficient sample size, but from this competitive analysis, it is clear that the quality policies and practices are not the same across semiconductor suppliers.

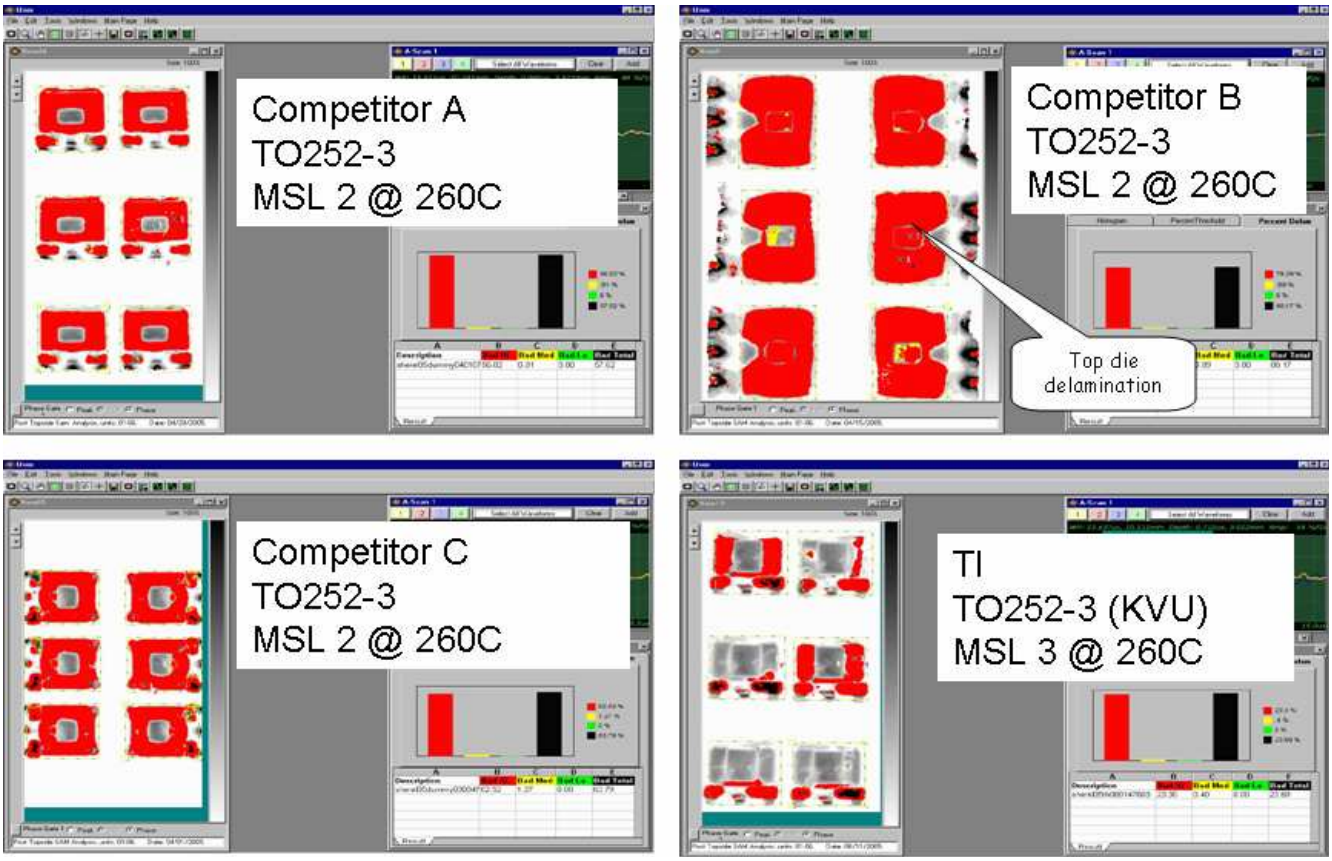

Figure 7. TO252-3 Post MSL Results

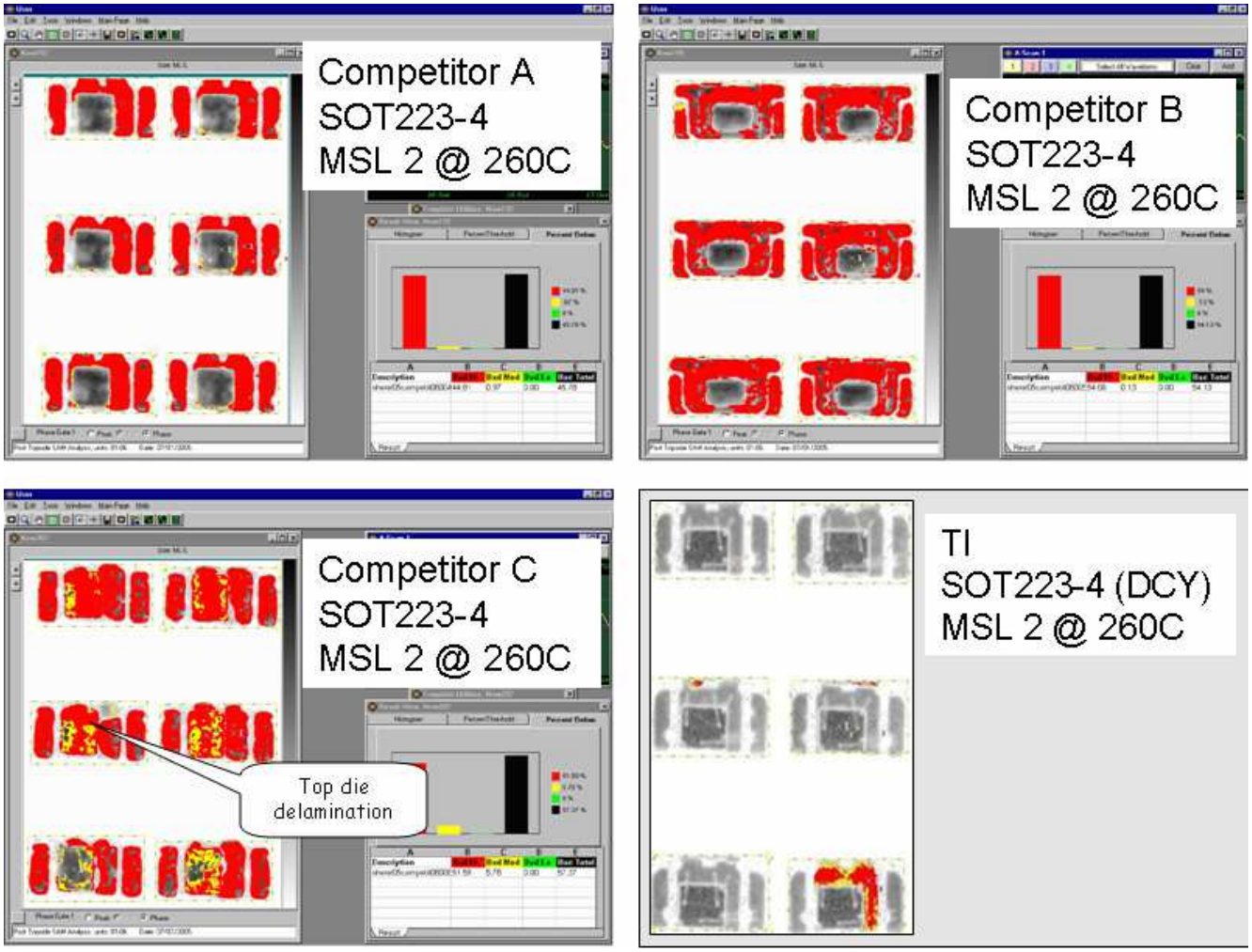

Figure 8. SOT223-4 Post MSL Results

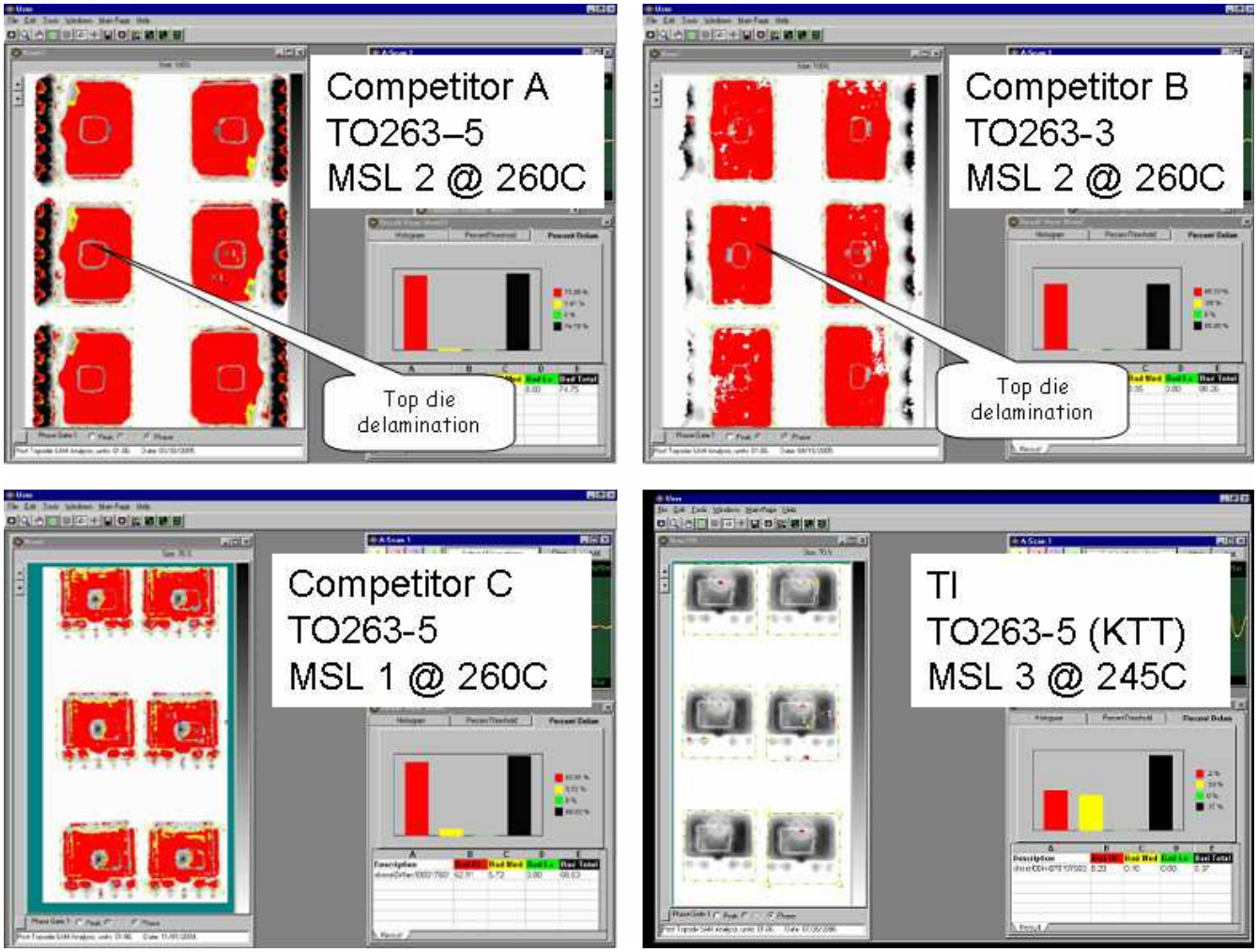

Figure 9. TO263 Post MSL Results

4 Conclusion

Delamination is not a desired result in packages as it can impact device reliability. However, due to package construction, cost pressures, and reflow temperature requirements, it is inevitable on some devices. There are several techniques that can be used to improve the delamination performance or improve reliability, but they do not come without a price. This document recommends that more attention be paid to delaminated areas within a package by doing post stress investigations and evaluating different mitigation techniques. These practices, along with the appropriate MSL rating, can lead to improve flange-mount packaging reliability.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
RFID	www.ti-rfid.com	Telephony	www.ti.com/telephony
Low Power Wireless	www.ti.com/lpw	Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265