National Semiconductor

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Package Reliability

All products and packages offered by National Semiconductor Corporation meet the minimum reliability qualification requirements outlined in *Table 1* and *Table 2* for hermetic and plastic packages, respectively. These minimum requirements are applied to new packages as well as to existing packages in which changes in material and/or assembly procedures and processes have occurred.

NSC offers a diverse line of products to many market areas with commercial, military, and aerospace applications. Due to the unique requirements of each customer application, NSC packages and products are subjected to customized qualification plans. Detailed qualification plans are determined by the appropriate NSC Product Group (including the Military/Aerospace Products Division) and the Reliability and Quality Assurance Department.

The reliability tests and conditions outlined below are used by NSC as a guideline for constructing a qualification plan rather than being used as a stand-alone qualification plan. Some test conditions are based on recommendations from MIL-STD-883 for hermetic packages, while those for plastic packages are either extended from MIL-STD-38510 for ruggedized plastics, JESD-22 for automotive applications, JESD-26 for rugged applications, or internally developed based on the majority of customer requirements. The sample size for each test outlined below is determined by Lot Tolerance Percent Defective (LTPD) and may vary between Product Groups. In an effort to achieve higher package/product quality levels, some of the tests identified below may be under review for modification to the test conditions, which may include preconditioning requirements.

For information concerning specific qualification plans for a particular package or product, please contact your local NSC sales representative.

TABLE 1. Qualification Requirements for Hermetic Packages

Test	Test Condition
Operating Life	Continuous operation at rated supply voltage; Ambient temperature is 125˚C; Test duration is 1,000 hours
High Temperature Storage	Continuous storage in air; Non-operating ambient temperature is 150˚C; Test duration is 1,000 hours
Temperature Cycle	Alternating hot and cold air; Non-operating extremes are −65˚C to +150˚C with no ambient dwell; Test duration is 1,000 cycles.
Power Cycle	Device electrical load cycled “ON” and “OFF” as required to cycle junction temperature between room ambient and maximum T rise; Test duration is 500 hrs
Thermal Shock	Alternating hot and cold fluids; Non-operating extremes are -65˚C and +150˚C with no ambient dwell; Test duration is 100 cycles. This test is an alternative to Temperature Cycle.
Thermal Sequence	Termperature cycle; Thermal shock; Moisture resistance; and Hermeticity
Electrostatic Discharge	Human Body Model, 2,000V minimum (positive and negative); All pins to supply, ground and adjacent pins; 0Ω, 200V
SEM Inspection of Metalization	Examination of worst-case contacts, vias, oxide steps, etc.; Coverage must be >50% of design cross-sectional area
Thermal Resistance	Junction temperature <150˚C at maximum power and temperature ratings
Salt Atmosphere	Lead conditioning (bend) followed by 24 hour exposure to salt fog at 35˚C
Resistance To Solvents	Test per military standards per package type.
Lead Integrity	Condition as appropriate to package style A) Tension, 8 ounces for 30 seconds; B) Bending, 15˚ arc; B2) Lead fatigue, 3 bends with weight applied; C) Torque
Solderability	Eight (8) hour steam age, followed by 5 second dwell in solder at 245˚C, 95
Solder Heat	Twelve (12) second dwell in solder at 260˚C; No physical or electrical degradation
Bond Integrity	Two (2) pass hot functional (or continuity) test at ambient temperature or 100˚C minimum
Mechanical Sequence	Mechanical shock; Vibration variable frequency; Constant acceleration; Hermeticity
Internal Water Vapor Content	100˚C, 5,000 ppm maximum
Low Temperature Life	Continuous operation at voltage greater than maximum rated supply voltage; Operating extreme of −40˚C; Test duration is 1,000 hours
Data Retention (EPROM)	Continuous storage in air; Non-operating ambient temperature of 200˚C; Test duration is 500 hours
Memory Endurance	Program/erase cycle; Bake at 150˚C; Electrical test; Test duration is 100k cycles
Packing Drop Test	NSC SOP-5-242

TABLE 2. Qualification Requirements for Plastic Packages

Test	Test Condition
Operating Life	Continuous operation at rated supply voltage; Ambient temperature is 125˚C; Test duration is 1,000 hours
High Temperature Storage	Continuous storage in air; Non-operating ambient temperature is 150˚C; Test duration is 1,000 hours
Temperature Cycle with Pre-conditioning (Note 1)	Alternating hot and cold air; Non-operating extremes are -65˚C to +150˚C with no ambient dwell; Test duration is 1,000 cycles. For BGA packages the non-operating extremes are -45˚C to + 150˚C.
Power Cycle	Device electrical load cycled “ON” and “OFF” as required to cycle junction temperature between room ambient and maximum T rise; Test duration is 500 hrs
Temperature Humidity Bias with Pre-conditioning (Note 1)	Continuous operation at rated supply voltage and minimum power; Ambient temperature is 85˚C; RH is 85%; Test duration is 1,000 hours
Autoclave with Pre-conditioning	Continuous storage in saturated steam; Non-operating ambient temperature is 121˚C; Pressure is 15 psi; Test duration is 500 hours
Biased Pressure Pot	Continuous storage in saturated steam with rated supply voltage applied between supply and ground pins; Ambient temperature is 115˚C; Pressure is 10 psi; Test duration is 168 hours
Thermal Shock	Alternating hot and cold fluids; Non-operating extremes are -65˚C and +150˚C with no ambient dwell; Test duration is 100 cycles. This test is an alternative to Temperature Cycle.
Electrostatic Discharge	Human Body Model, 2,000V minimum (positive and negative); All pins to supply, ground and adjacent pins; 0Ω, 200V
SEM Inspection of Metalization	Examination of worst-case contacts, vias, oxide steps, etc.; Coverage must be >50% of design cross-sectional area
Thermal Resistance	Junction temperature less than 150˚C at maximum power and temperature ratings
Resistance To Solvents	1) Alcohol & mineral spirits; 2) BIOACT EC7; 3) Loncot Erge #520 detergent (or equivalent).
Lead Integrity	Condition as appropriate to package style A) Tension, 8 ounces for 30 seconds; B1) Bending, 15˚ arc; B2) Lead fatigue, 3 bends with weight applied; C) Torque
Solderability	Eight (8) hour steam age, followed by 5 second dwell in solder at 235˚C; rosin-based flux; 95 coverage
Solder Heat	Twelve (12) second dwell in solder at 260˚C; No physical or electrical degradation
Bond Integrity	Two (2) pass hot functional (or continuity) test at ambient temperature or 100˚C minimum
Flammability	UL-94, V-0
Memory Endurance	Program/erase cycle; Bake at 150˚C; Electrical test Test duration is 100k cycles

Note 1: Pre-conditioning stress sequence defined in NSC specification RAI-5-039.

Reliability Issues

Integrated circuit packages are subjected to many stringent qualification tests prior to actual use. These tests cover the standard qualification procedures outlined in *Table 1* and *Table 2* such as static high temperature life, autoclave, operating life, thermal cycling, thermal shock, or high temperature storage life — just to name a few. Although the name of the tests may be the same, conditions can vary among the IC suppliers and system houses (1). Except for standards for hermetic packages such as MIL-STD-883, industry-wide test standards for plastic packages do not exist. Each company sets its own test conditions best suited for its product lines or its own customer specifications.

Qualification tests impart varying extent of stresses on the packages, which may ultimately lead to different modes of failures. The purpose of such tests is to accelerate any potential failure mechanism, which may occur during actual operation. The important consideration is to insure that the proper failure mode is accelerated, and that newer mechanisms are not introduced by selecting the incorrect test conditions.

The typical environments encountered by IC packages are listed in *Table 3*, ranging from the most benign environment such as computers installed in a temperature-controlled office, to the harsher automobile hood area, to the much more critical military platforms such as missiles being launched.

Thus, ICs can be assembled on systems that have various degrees of ruggedness, where dependability is desirable in all cases, and critical in others. However, due to the assembly conditions and construction nature of the IC packages, environmentally-induced stresses can shorten the mean lifetime of the devices. *Figure 1* illustrates some of the common modes of failures which may occur either due to assembly conditions or to external stresses imposed during operation.

Assembly-induced defects can range from poor bonding interfaces, wire sweep, voids in the die attach, to voids in the

Reliability Issues (Continued)

molding compound. Poor bonding may result in marginal bond interfaces that may not be readily detected during initial screening and testing. Only after the packages have been subjected to some thermal cycles or shocks that problems such as circuit opens or shorts develop.

Wire sweep, caused by a combination of unoptimized bonding conditions and die bonding layout, results in wirebonds that are pushed close to each other, and in some cases, touching either other wires or the die edge, shorting the device (2). Such defects can easily be detected by X-ray. Eliminating those defects, however, is much harder and requires a systematic approach to die design, from reconfiguring the bond pads, to minimizing wire lengths, to controlling the mold compound flow into the packages.

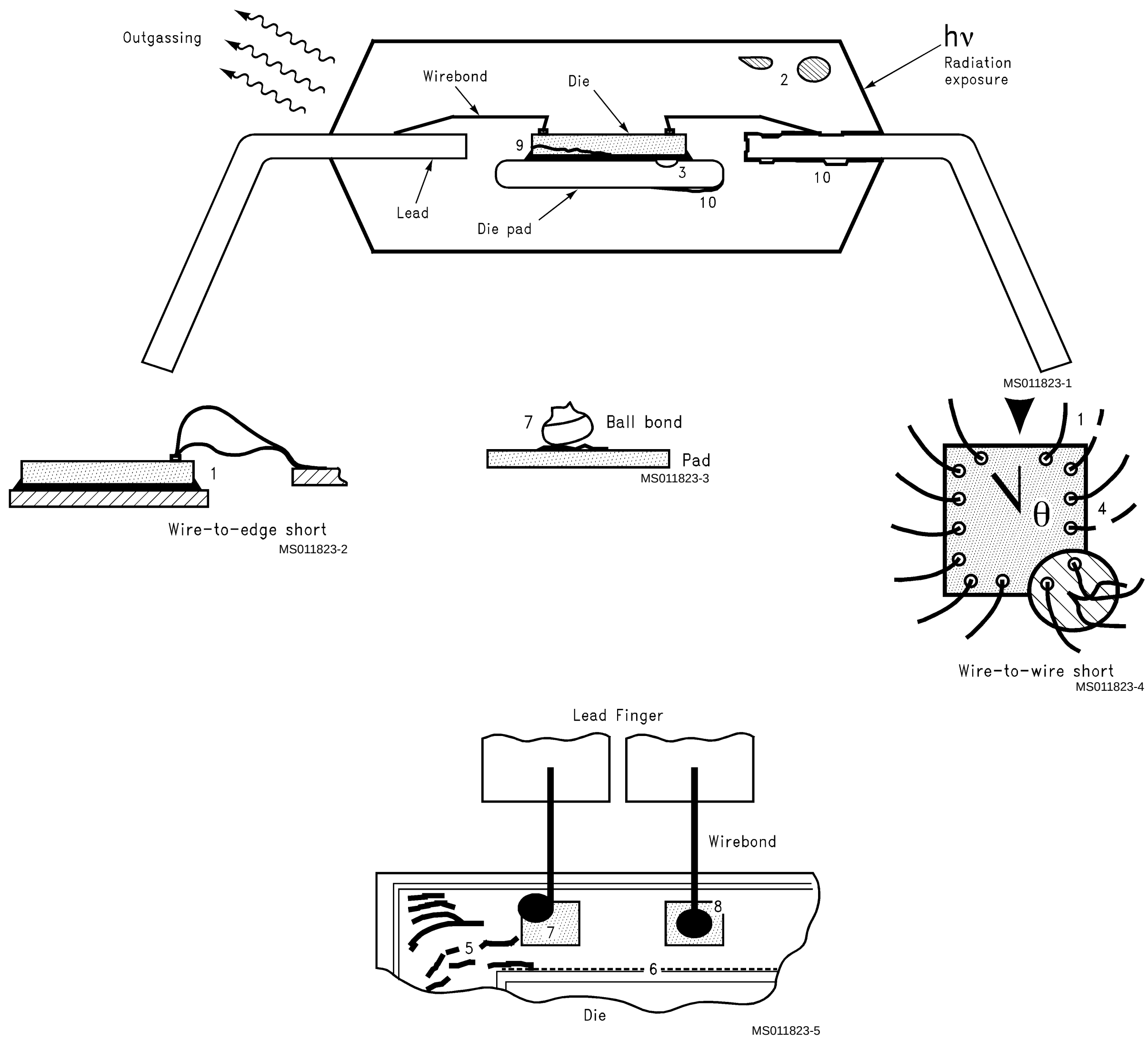
TABLE 3. Typical Environmental Stresses Encountered by Packages Assembled on Different Platforms to be Used in Different Environments (1)

Applications	Environmental Stresses
Computers, PCs, Workstations (Note 2)	Thermal shock, solder exposure, shock, vibration, fatigue, flammability, solvent exposure, temperature/humidity/bias, overload, RF/EMI, ESD; Mfg. Proc. (+25˚C to +260˚C); Storage (−40˚C to +85˚C); Operation (0˚C to +55˚C)
Automobile (Note 2)	Thermal shock/cycling, temperature extremes, shock vibration, overload, surge, solvent exposure, flammability, EMI; Mfg. Proc. (+25˚C to +260˚C); Storage (−55˚C to +125˚C); Operating (−40˚C to +125˚C)
Missile, launch (Note 3)	Pyrotechnic shock, random vibration, acceleration, temperature/humidity/altitude, load shock, thermal shock/cycling, acoustical noise, EMI, sine vibration, humidity, temperature extremes, pressure shock, altitude, space simulation, explosive atmosphere; Mfg. Proc. (+25˚C to +260˚C); Storage (−62˚C to +71˚C); Operating (−40˚C to +125˚C)

Note 2: From suggestions of the Surface Mount Council, *"Status of Technology Industry Activities and Action Plan,"* (IPC & EIA) (1992).

Note 3: From RADC *"Nonoperating Reliability Databook"* (1987).

Reliability Issues (Continued)



PACKAGING RELIABILITY ISSUES

1. Wire sweep/short
2. Void (epoxy)
3. Void (die attach)
4. Wire breakage
5. Passivation cracking and dielectric cracking
6. Metal line shift
7. Bond-non-stick/Cratering
8. Corrosion
9. Die cracking/chipping
10. Delamination
11. Outgassing
12. Radiation hardness

FIGURE 1. Typical Packaging Reliability Concerns Facing the User during Assembly and during Use

Reliability Issues (Continued)

Voids can be introduced during die attach from outgassing of the solvent-filled material or improper curing profiles. Generally, specifications exist within each company to regulate the size of acceptable voids, if any. The effects of die attach voids are generally subtle. Even small voids can affect the stress profiles of the die, which may not produce any metallization damage until the proper combination of materials (e.g., molding compound or die coating) and environmental conditions (e.g., large thermal excursions) are encountered. Furthermore, voids are air gaps that raise the thermal resistance of the package. In high power devices, poor heat dissipation can increase the junction temperatures dramatically, and effectively shortening their mean lifetimes.

Voids in mold compound are introduced during molding from a combination of factors (3). Packages molded in conventional systems contain typically more voids than those encapsulated in the newer multiplunger or “gang pot” systems. Air can be entrapped from operator mishandling of the pellets during preheating, or wrong selection of the pellet size for a given mold pot size, or poor mold cavity design resulting in imbalance between the top and bottom flows producing a “race track” effect which blocks venting, or from absorbed moisture outgassing at the high molding temperature. Voids in the compound are typically polydispersed in nature, and tend to be randomly distributed. As a result, void prediction is difficult due to the lack of a proper working model.

Long-term packaging concerns include stresses from the molding compounds, moisture absorption, moisture-induced corrosion, interfacial delamination, and high temperature stability (4).

Packaging Stresses

Packaging stresses arise from a mismatch in the coefficients of thermal expansion (CTE) of the various materials in the packages (5). For instance, the typical copper alloy leadframe has a CTE of 17 x 10^{-6}/°C. In comparison, the silicon die, the epoxy die attach, and the typical low stress molding compound have CTEs of 2.5 x 10^{-6}/°C, 15 x 10^{-6}/°C, and 20 x 10^{-6}/°C, respectively. Thus, the thermal excursions that are typically imparted to plastic-encapsulated packages, such as cooling right from molding or post mold cure, thermal cycling, and thermal shock can induce several modes of device failures (6). This can range from parametric shifts in stress-sensitive devices to “killer” defects such as metal line shift, passivation cracking, dielectric cracking, and in the worst case, cracking of the silicon.

Packaging stresses can be characterized by a variety of techniques, such as laser interferometry, X-ray diffraction, photoelasticity, bilayer bending beam, and piezoresistive gages. Each technique has its advantages and drawbacks. However, piezoresistive gages fabricated directly on the dies appear to be the preferred method for in situ measurement. When distributed over the die surface, such structures can provide useful information on the stress profile generated from processing effects, material interactions, or package configurations (7).

Molding-induced stresses can be countered with a combination of proper material selection, die design rules, and package configuration. Optimization of the materials of construction, however, is more than just choosing the lowest stress epoxy mold compound or die attach. Recent studies indicated that the combination of mold compound and die attach do not act synergistically to provide the package with the lowest stress imparted to the silicon. For instance, an ultra-low stress compound combined with an ultra-low stress die attach actually perform poorer than an equivalent package with an ultra-low stress compound and a standard die attach material. The main reason is that the low stress die attach formulation becomes quite flexible during thermal cycling or thermal shock, and causes the die to shift during the thermal excursion. Such motion combined with the already large shear stresses along the die periphery can worsen the problem.

Proper die design rules can minimize the effects of stresses on the die. Common guidelines include, for instance, positioning large bus bars away from the edges, slotting any large metal line to provide anchoring for the molding compound, or moving sensitive areas away from the die corners.

Package configuration changes can also affect the stress profiles on the die. Naturally, cavity packages such as hermetic packages do not experience molding stresses, although the die attach material does impose stresses on the die.

Coatings of silicone gel or polyimide buffer the effects of the molding compound on the die.

Moisture Permeation

Ceramic packages are hermetically sealed and do not suffer from moisture absorption. Plastic-encapsulated packages, on the other hand, are porous to moisture. When left under humid environments, the encapsulant absorbs water up to a saturation level which is determined by the chemical nature of the epoxy and the environmental conditions such as temperature and relative humidity (8–10).

Moisture can penetrate into the package via two routes, namely, bulk diffusion through the top and bottom sides of the package or diffusion by capillary action along the sides of the leads. An estimate of the influence of each route can be obtained with moisture sensors embedded in the packages and exposed to various conditions. Results showed that for molded packages, moisture penetrates through the top and bottom sides which are the two largest exposed areas. The balance is due to moisture creeping along the leads into the package. Although relatively minor, the latter mode of diffusion can dominate under poor assembly conditions. For instance, trim and form can damage the leads and introduce microcracks at the epoxy-leadframe interface. The ensuing loss of adhesion accelerates the transport of water into the package.

The composition of the molding compound dictates the amount of moisture absorbed by the package. Filler loading, filler type, filler distribution, and filler surface treatment all affect the diffusion characteristics. High filler loading, for instance, results in less resin and, therefore, less hygroscopic material to absorb moisture. Similarly, the aspect ratio of the fillers (e.g., circular vs. flake) governs the diffusion paths, with flakes providing more tortuousity to the permeating water molecules. Filler distribution dictates the maximum volume loading possible. Typically, multiple size distribution allows for much higher filler concentration than monodisperse distribution, since the smaller particles can fit within the voids formed by the larger size fillers. Finally, treating the fillers with silane coupling agents enhance adhesion and minimize the interfacial voids that would facilitate moisture retention by the encapsulant.

The hygrothermal history of the encapsulant also controls the extent of moisture absorption. When the compound is cured fast, the resulting epoxy network is less dense than a

Moisture Permeation (Continued)

network produced by a slower and longer heating profile. Higher water absorption is obtained with the former network. Once water has permeated the encapsulant, however, some permanent damage to the epoxy such as network dilation and swelling-induced microcracks is imparted. Even after the part is baked, reexposure to a wet environment always results in a higher saturation level.

Moisture-Induced Corrosion

The presence of a moisture film at the die surface is needed to induce any corrosion. Humidity and temperature act in unison to induce various moisture-related defects such as parametric shifts, line corrosion, and pad corrosion (11). Moisture can be introduced into the packages in humid environments such as nonoperating long term storage, or qualification tests such as autoclave, temperature/humidity/bias, or HAST (12).

The moisture-induced corrosion can be broken down into four major steps, namely, moisture diffusion into the molding compound, diffusion through the passivation layer, transport of ionic contaminants to the potential corrosion site, and electrochemical reaction between water and the various ionic constituents (13).

Diffusion into the plastic encapsulant is taken for granted from the hygroscopic nature of the epoxy. Diffusion through the passivation layer is a much slower step that occurs nevertheless when pinholes or stress-induced microcracks exist. Even though water surrounding the package may be pure, by the time it reaches the die surface, ionic species along the diffusion paths may also be entrained. The contaminants can be either external (e.g., flux residues) or internal (e.g., catalyst leftovers from the polymerization reaction). Free ions such as Cl^- can continuously attack any exposed aluminum in the presence of water.

Moisture-induced corrosion in plastic-encapsulated packages can be minimized by considering the following options either singly or in combination: 1. Reduce the ionic content by selecting purer molding compounds; 2. Use "ion scavengers" that can be incorporated directly into the compound formulation; 3. Enhance the interfacial adhesion between the molding compound, the die, and the leadframe; and, 4. Use compound formulation with higher filler content, and therefore, less weight absorption per unit volume. None of the previous options completely eliminates the potential for moisture-induced corrosion. Only by making the die "bullet proof", e.g., covering the surface and any exposed aluminum with inorganic impermeable coatings, that corrosion can be completely eliminated.

Adhesion/Delamination

The loss of adhesion at an interface, known as delamination, occurs in packages due to either surface contamination or excessive shear stresses. Surface contamination degrades the interfacial strength. Oxidation of the leadframe during the die attach step, for instance, is a prime example. The copper oxide forms a weak interface with the molding compound. Such interface may degrade during subsequent processing operations. On the other hand, when the local shear stresses exceed the bond strength, interfacial delamination ensues. Since high stresses are observed in the vicinity of geometric discontinuities such as die corners and die pad edges, delamination typically is initiated around such areas. Thermal excursion incurred during post assembly processing can be sufficiently severe to induce delamination (14).

Aside from contamination and thermal stresses, poor adhesion can also be due to partial degradation of the interface due to moisture absorption. Scanning acoustic microscopy conducted on packages that were preconditioned to various levels of moisture revealed a change in signal intensity with higher moisture content (1). Swelling of the epoxy network, accompanied by plasticization of the matrix leading to a lowering of the modulus and glass transition temperature, accounts for the changes at the epoxy interface.

Another cause for interfacial delamination is the familiar "popcorn" effect encountered during assembly (15,16). The plastic packages absorb a certain critical level of moisture, which if not baked out properly, will turn into explosive steam at reflow conditions. The steam needs an escape route out of the packages. In most plastic-encapsulated ICs, this translates into a deformation of the die pad underside since this is the largest area in the packages. If the epoxy is sufficiently robust to resist the internal steam pressure, no package cracking occurs, although some extent of delamination may be observed. However, in the worst case, cracking of the epoxy is typically recorded. Depending on the package configuration, the cracks can be single or double-sided, and can either propagate upward from the die or downward from the edge of the die pad (1,16).

Delamination can be minimized or even eliminated completely. This goal requires a multi-faceted approach of selecting the proper epoxy resin chemistry, improving the resin wettability to the package components, and reducing the hygroscopic nature of the resin. The proper resin chemistry incorporates the optimal concentration of coupling agent (to enhance adhesion of the matrix to the fillers), adhesion promoter (to enhance adhesion of the matrix to the die and the leadframe), and release agent (to facilitate removal of the packages from the mold cavities). On the other hand, resin wettability can be improved with lower resin and hardener viscosities. And, finally, moisture uptake is reduced by using hardeners with higher functionality or less hygroscopic groups in the polymer chains.

Outgassing Impurities

High temperature stability of plastic-encapsulated packages is a relatively new reliability concern that is set by standard JESD-22, Method A103. Typically, packages would be heated to at least 175˚C for over 1,000 hours. Such conditions are supposed to simulate the thermal environment in power devices where high junction temperatures are expected. Operation at high temperatures can affect the flammability of the plastic packages. Thus, flame retardants made up of halide complexes are generally added to the compound formulation to suppress the initiation and propagation of the fire front (17,18). Concentrations less than 10 parts per million are usually sufficient to meet UL standards.

At the high test temperature, the epoxy molding compound outgasses, releasing in the process fumes that can be detrimental to the device (19). The outgassing fumes can originate from the epoxy resin, the silicone modifiers added for low stress, and the halide agents (typically, bromine and antimony oxide complexes). The resulting mode of failure involves intermetallic growth between the gold wirebond and the aluminum bond pad. The porous intermetallic layer causes an increase in bond resistance until an "open" registers.

Outgassing Impurities (Continued)

Several approaches currently exist to minimize halide-induced intermetallic growth. For instance, epoxy resins with high glass transition temperatures can be formulated since a dense network translates to a slower diffusion of the contaminants. Also, more thermally stable brominated epoxies can also be compounded with standard epoxy resins to reduce outgassing. Another approach involves incorporating highly reactive antimony oxide. The rationale is that at high temperatures, the antimony oxide breaks down and combines with the bromine ions released from the epoxy matrix, impeding the growth of intermetallic growth. And, naturally, reducing the content of the bromine in the molding compound to the minimum level which satisfies the UL requirements, while adjusting the antimony oxide content would help. The synergistic mechanism between bromine and antimony oxide is less well understood, although the failure rate of Au-Al intermetallics has been shown to decrease.

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Notes

National Semiconductor Corporation
Americas
Tel: 1-800-272-9959
Fax: 1-800-737-7018
Email: support@nsc.com

www.national.com

National Semiconductor Europe
Fax: +49 (0) 1 80-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 1 80-530 85 85
English Tel: +49 (0) 1 80-532 78 32
Français Tel: +49 (0) 1 80-532 93 58
Italiano Tel: +49 (0) 1 80-534 16 80

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: sea.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507