Life Prediction Methodology For A Discrete Transistor Package

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Abstract

Motorola has recently introduced a new package, called Powermite\textsuperscript{4} for the portable product market in applications (cellular phone, notebook computers, battery chargers), where size and performance are critical. Powermite is a surface mount rectifier package that is half the size of the industry standard SMA rectifier package. As with all Motorola discrete packages, the Powermite package must meet the mechanical, thermal, electrical, and reliability requirements. Computer simulations, using ANSYS\textsuperscript{4}, were used to verify that the Powermite would satisfactorily meet the stringent Motorola qualification requirements. Of particular concern was whether the solder joint for die attach to the leadframe cathode heat sink would survive the severe thermal cycling (-65°C to 150°C) requirement for these parts. Thermal cycling induces thermal mechanical loading to the package assembly due to the differential thermal expansion of package materials. Solder is particularly vulnerable to fatigue damage since the loading manifest as a high strain energy at the solder interface. This paper describes an analytical solder reliability (failure prediction) methodology, developed by Darvaux et al.\textsuperscript{6}, used to quantify the solder fatigue life for the Powermite package. The methodology accounts for the inherent viscoplastic behavior of the solder in microelectronics packages over the operating life of the package. The solder life prediction is compared with on-going reliability thermal cycling testing of the Powermite package. The methodology described in this paper for characterizing the solder reliability can be applied to other packages but not limited to micro-miniature electronic packages.

Key words:
Plastic Package, Solder, Thermal Mechanical, Thermal Stress, Viscoplasticity, Fatigue, Reliability, and DO216AA.

1. Introduction and Overview

1.1. The Powermite Package

Powermite devices are an advanced series of high performance, Schottky rectifiers in a micro-miniature, space saving surface mount package (Figure 1). These miniature surface mount rectifiers feature low \( V_f \) and low leakage in a very small package. The Powermite...
package occupies 50% less board area than SMA (Figure 2) and is slightly larger than the industry standard SOT–23. The Powermite has a low profile of 1.1mm (43.3 mil) and a small footprint of 8.45 mm² (0.0131 in²).

![Figure 1. Powermite Schottky rectifier used in low voltage and space saving applications.](image1)

![Figure 2. Powermite is 50% smaller than SMA package.](image2)

Powermite Schottky rectifiers (P/Ns MBRM120T3 and MBRM140T3) are designed for use in low voltage applications where efficiency, low leakage, and size/height are important. Low Vf provides higher efficiency and extends battery life. Measuring 1.1 mm (43.3 mil) in height, this miniature package is slightly larger than a SOT-23, while delivering the thermal and electrical performance of an SMA rectifier package. Due to their small size, they are ideal for use in portable and battery powered products such as cellular and cordless phones, chargers, notebook computers, printers, PDAs and PCMCIA cards. Typical applications are AC/DC and DC/DC converters, reverse battery protection, and “Oring” of multiple supply voltages.

1.2. Thermal Stress And Solder Fatigue

One of the dominant failure mode for this type of package is solder fatigue. Solder fatigue overview are provided in References 4, where it is described that the solder reliability is largely governed by the material thickness and laminate layout, material modulii, and Coefficient of Thermal Expansion (CTE) mismatch, processing quality, and thermal (or service) environment.

Solder is particularly susceptible to failure since it can undergo significant inelastic deformation. Solder failure often occurs by fatigue cracking through the intermetallic layer at a joint interface. One important design aspect in electronic packaging is the understanding of solder deformation kinetics. For many applications, the package operating temperature pushes the solder close to its melting temperature which causes the deformation kinetics to be dominated by creep. Creep is a rate dependent material nonlinearity in which the material irreversibly deforms under a constant load. As temperature and thermal exposure times are elevated, the creep deformation is more pronounced.

The focus of this paper is to apply a design methodology for evaluating the solder joint reliability by evaluating the solder deformation, solder fatigue life prediction, and comparing the results to experimental measurements.

1.3. Solder Reliability Model Overview

To quantify the thermal stress effects on the solder reliability, the task requires an accurate representation of the deformation kinetics of solder. Darvauex et al., Reference 6, outlined a generalized solder joint failure prediction methodology for creep rupture and thermal fatigue for various solder alloys, as well as providing analytical techniques and the basic data necessary to complete this task. This analytical technique, while focused in the Ball Grid Array (BGA) package type, was successfully used by the Motorola, Semiconductor Component Group, and Power Products to evaluate the integrity of solder joints in their Hybrid Power Modules used for the improvement (high current) of electric motor efficiency.

Darveauex, et al. concluded that solder alloy deformation can be described for a wide range of conditions using a set of defined constitutive relations. The deformation behavior of different alloys can be described by the same set of relations, where only the deformation parameters are alloy dependent. Secondly, both time dependent creep and time-independent plastic flow occur simultaneously in many solders. Solder responds rapidly to the thermal mechanical effects by plastically deforming and converting this action into viscoplastic flow in the form of strain energy. Therefore, the deformation is a function of time, temperature, and thermal mechanical stress.

The solder joint reliability (life prediction) model is based on the inelastic strain energy density (or plastic work) per cycle by calculation using nonlinear Finite Element methods. The model uniquely separates the initiation and propagation lives as a function of the plastic work. Darveauex et al. procedure, to estimate solder joint reliability, is provided in Reference 6, but is summarized as follows,

i. Calculate the solder joint strain energy density distribution using Finite Element Analysis.

ii. Calculate the crack initiation life for the worst case joint with the largest strain energy.

iii. Identify the characteristic crack length that would induce malfunction of the component.

iv. Calculate the crack propagation life based on the characteristic crack length for the worst case joint.

v. Total life of the joint is taken as the sum of the initiation and the propagation lives.

This methodology was applied to over 50 data sets from thermal cycle tests on TSOP, CBGA, and PBGA packages. A plot of the
predicted failure free life versus the measured failure free life is shown in Figure 3. It is seen that the model gives good correlation over two orders of magnitude in failure free life. Only two data sets fall outside the +/-2x bands, and the model was conservative on both of those (measured life was greater than predicted life).

Figure 3. Measured versus predicted lives.

2. Finite Element Modeling (FEM)

2.1. Overview

ANSYS5.3 was used in creating the Powermite package geometry, Finite Element discretization, and analysis. The resulting Powermite package Finite Element model is shown in Figure 4. Half symmetry modeling captured the pertinent features of the Powermite package including the epoxy mold compound, the copper lead frame and the clip, the silicon die, and the 88Sn10Pb2Ag solder die attach. Also modeled, but not shown in Figure 4, was the Level 2 packaging of the Powermite which was mounted on a polyimide board using solder (96.5Sn3.5Ag).

Figure 4. Powermite package and the half symmetry FEA model.

Aside from the solder die attach material with the die, ANSYS5.3 3D brick Finite Elements (Solid45) were used. Viscoplastic elements (Visco107) were used for the 88Sn10Pb2Ag solder. The analysis was run with and without the polyimide board. The polyimide board 96.5Sn3.5Ag solder attach was modeled using a multi-linear isotropic hardening.

2.2. Materials

The materials that make up the package include a low stress epoxy mold compound, a thermally conductive alloy for both the cathode and the anode leads, the 88Sn10Pb2Ag solder die attach, and the top surface bump for lead frame clip attachment. No wirebonds are used in this package. Rather a clip is directly attached to the active surface of the die using solder. Also, as mentioned earlier, the package was attached to a single layer polyimide board using 96.5Sn3.5Ag solder.

2.3. Physical Dimensions

The Powermite package is a registered JEDEC standard DO-216AA. The overall case dimensions of the Powermite package are provided in Reference. As summary, the outside case dimensions of the package are approximately given by 75 mil². The die dimensions are 40 mil² by 10 mil (0.254 mm) thick. The leadframe thickness was 6 mil (0.152 mm), and the solder die attach thickness was 1 mil (.025 mm). The package was mounted on a 0.5 inch x 0.63 inch x 0.03 inch thick (1.27 cm x 1.60 cm x 0.08 cm) polyimide board using 96.5Sn3.5Ag solder which was also set to 1 mil (.025 mm) thick. The board is similar to that used in the reliability thermal cycling testing.

2.4. Material Properties and Behavior

The Semiconductor Research Council provided funding to Purdue University and CINDAS Microelectronics Packaging Materials Database was used for determining the isotropic linear mechanical properties of the various materials modeled. The significant temperature dependent properties of interest included the temperature dependency of the elastic and shear modulii, CTE, Poisson’s ratio, and stress strain behavior of the solder systems. Other sources for properties were found in References.

The CTE properties for 10Sn88Pb2Ag (liquidus 290°C) were unavailable in CINDAS. As approximation, the CTE properties of 5Sn95Pb (liquidus 301°C) were used as substitute. The CTE data for all materials were modified per the corresponding stress free temperature for the given material. The stress free temperature is a function of processing of the package, which is described in a later section.

The temperature dependent stress strain behavior of the 96.5Sn3.5Ag (liquidus 221°C) solder was used since the package interconnect layer was modeled using isotropic hardening principle along with the Von Mises yield criteria since large strains likely would occur in this layer.

The Anand’s model for rate dependent plasticity or viscoplasticity was used to model the material behavior of the 10Sn88Pb2Ag solder die attach interconnect. Viscoplasticity is characterized by the time dependent irreversible plastic straining which, consequently, is a function of the strain rate. The strain rate...
is directly affected by the rate and duration of the applied thermal loading due to processing and through its operational life. Instead, plastic flow is assumed to take place at all non-zero stress values although at low stress the rate of plastic flow may be immeasurably small\textsuperscript{16}. While Anand’s model does not take into account the time-independent plastic flow, its influence was captured in the Finite Element analysis through the deformation constants. The deformation constants include both time-dependent and time-independent phenomenon, since it was concluded that time-independent plastic flow and time-dependent creep occur simultaneously in solder\textsuperscript{17}.

Reference\textsuperscript{6} provided the Anand deformation constants for six solder systems including: 62Sn36Pb2Ag, 60Sn40Pb, 2.5Sn97.5Pb, 96.5Sn3.5Ag, 100In, and 50In50Pb. The data were collected on actual soldered assemblies which captures the effects of grain size and intermetallic compound distribution\textsuperscript{10}. Since the Anand deformation constants for 10Sn88Pb2Ag are not available, it was assumed that they would be represented by 97.5Pb2.5Sn (liquidus 320°C) whose Anand’s parameters and the corresponding ANSYS Anand model coefficients are provided in Table 1. Using this material should be conservative since the addition of silver (Ag) tends to lower the steady state creep rate. For instance, although the stress-strain rate behavior at 2% strain is essentially identical between 62Sn36Pb2Ag and 60Sn40Pb, the steady state creep rate\textsuperscript{6} for 62Sn36Pb2Ag is half that of 60Sn40Pb.

Table 1. Anand’s deformation parameters.

<table>
<thead>
<tr>
<th>Anand’s Parameter</th>
<th>ANSYS Coefficients</th>
<th>Solder 2.5Sn97.5Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>So (psi)</td>
<td>C3</td>
<td>1</td>
</tr>
<tr>
<td>Q/R (1/K)</td>
<td>C2</td>
<td>13330</td>
</tr>
<tr>
<td>A (1/s)</td>
<td>C3</td>
<td>2.2E+08</td>
</tr>
<tr>
<td>ξ</td>
<td>C4</td>
<td>1.4E-03</td>
</tr>
<tr>
<td>m</td>
<td>C5</td>
<td>0.142</td>
</tr>
<tr>
<td>ho (psi)</td>
<td>C6</td>
<td>1.09E-09</td>
</tr>
<tr>
<td>σ* (psi)</td>
<td>C7</td>
<td>1</td>
</tr>
<tr>
<td>n</td>
<td>C8</td>
<td>1.09E-09</td>
</tr>
<tr>
<td>a</td>
<td>C9</td>
<td>1.3</td>
</tr>
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</table>

3. Finite Element Analysis

3.1. Boundary Conditions

The Powermite package Finite Element model was used to evaluate the effect of package manufacturing and subsequent reliability thermal cycling. The manufacturing process of die attach and molding was considered since such processing induces internal residual stress. Such processing has significant effect on the residual strain energy density experienced by the solder. The boundary conditions applied to the model included displacement constraints, stress free reference temperatures, and isothermal loading that were applied as a function of time.

The physical restraints applied to the model (Figure 4) included: (1) the nodes in the cutting plane of the half symmetry model were fixed normal to that axis (for example, the y-direction); (2) rigid body translations and rotation were prevented by fixing the appropriate nodes in the X and Z directions along the leads. These boundary conditions permitted volumetric thermal shrinkage and expansion in all three directions.

The stress free temperatures or reference temperatures applied throughout the analysis was based on the sequential processing temperatures used in the Powermite package manufacture. The thermal expansion coefficients were calculated and reference to the appropriate reference temperature.

Die attach to the leadframe is performed at approximately 310°C. Figure 5 provides the thermal loading profile as a function of time that was used to represent the bulk temperature of the system. The load profile is based on thermal measurements used in a similar solder reflow process as described in Reference\textsuperscript{17}. Using the ANSYS element birth and death procedure, Reference\textsuperscript{16}, only the die, the leadframe, and the die attach solder were activated.

Next, the elements making up the Powermite package were all activated following the overmolding of the package at a peak processing temperature of approximately 165°C. Following this load step, the package was analyzed at a storage temperature of 25°C for 24 hours (86400 seconds). This process was performed to capture any residual creeping or strain redistribution that might possibly occur in the solder joint. Such is the benefit of utilizing the Anand’s plasticity model. For these simulations, the elements making up Level 2 packaging were deactivated.

Finally, the package and Level 2 packaging materials (solder and polyimide board) were attached using a similar reflow process as the die attach, but with the peak process temperature set to 240°C. Following the Level 2 packaging, all the elements in the model were activated for subsequent reliability thermal cycling, Figure 6.
Life Prediction Methodology For A Discrete Transistor Package

Thermal cycling was applied using bulk temperature definition for the various time steps representing the thermal cycle used in the qualification testing of the Powermite package. The cycle was defined using a 65°C minimum and a 150°C maximum temperature excursion (ΔT=215°C). The ramp period between the temperature extremes was 15 minutes and the dwell time was 60 minutes. Three thermal cycles were evaluated per the findings in References 17-19. By the third thermal cycle, the change or accumulation of plastic work (such as the strain energy density) is small, thereby indicating the stress–strain hysteresis loop has stabilized.

Overall, 30 load steps were used to represent about 60 hours of manufacturing processing and thermal cycling. The ANSYS5.3 analysis was performed on a Silicon Graphics, Indigo 2 workstation which was equipped with the R10000 processor20 and 156 Mbytes of RAM. The computation time was about 14 hours.

3.2. Solder Viscoplastic Analysis Results

Following the successful convergence of the analysis, the results were evaluated to extract the viscoplastic strain energy density (plastic work/volume, units: psi) in the die attach solder joint. The strain energy density is the summation of the product between stress and inelastic strain increment vectors over the converged subsets.

Shown in Figure 7, is the strain energy density distribution in the joint after the third thermal cycle. The peak strain energy density was highest at the edge of the joint (for example position furthest from die center axis) on the side furthest from the cathode lead. As was found in Reference6, the majority of the strain energy density accumulated in this solder joint occurs during the manufacturing process. Thermal cycling merely increases the plastic work at a much slower yet linear increasing rate.

For information purposes, Table 2 provides the cyclic maximum range in strain energy and the total (Von Mises equivalent) strain range. The maximum strain energy range is used in the next section to determine the cycles for crack initiation. The total strain range can be used to compare the predicted lives using the Coffin-Manson life approach described in Reference6.

<table>
<thead>
<tr>
<th>Max. Strain Energy Range, ΔW_e (psi)</th>
<th>Max. Equivalent Strain Range, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>2</td>
</tr>
</tbody>
</table>

4. Reliability Life Predictions

4.1. Methodology

The reliability model that was used in this study provides the relationship between cycles to failure and the rate of change of plastic work. The life prediction model is based on superposition of the number of thermal cycles (-65°C to 150°C) to induce crack initiation (Ni) and crack propagation (Np) to subsequent failure of the die attach solder joint. The total number of cycles to failure, N, is defined by,

\[ N = N_i + N_p \tag{1} \]

The relationships for initiation and propagation cycles to failure are based as a function of the incremental change in strain energy density (ΔW) of the plastic work. Development of the equations are thoroughly described, applied, and compared to test results in References6,8-11,17,19,21. Based on this earlier work, the correlations used in this study are as follows,

\[ N_i = \frac{20,000}{\Delta W_i} \tag{2} \]

\[ N_p = a_i / (\Delta a_i / \Delta N) = a_i / (2.38E-7 \Delta W_p 1.15) \tag{3} \]

where ΔW_i (psi) is the incremental change of the maximum strain energy density for one full thermal cycle; Δa_i/ΔN (inches per cycle) is the linear crack growth rate; and a_i is the characteristic crack length (inches) in the joint that induces device malfunction; and ΔW_p (psi) is the incremental change in strain energy for one thermal cycle which is averaged over the characteristic crack length. The crack initiation and propagation correlation prefactors and exponents, included in Equations 2 and 3, were based on the recommendations discussed Reference6 for accounting for elemental thickness Finite Element mesh density used in the Powermite model (Figure 4). In the analysis post processing, the strain energy density range, ΔW, was extracted based on the last (for example, the third) simulated thermal cycle.

The predictive technique has proven to be effective over a wide range of conditions and package technologies. However, it does have some limitations. The Finite Element analysis results are very sensitive to mesh density21. As element size is reduced, the calculated strain energy density increases. This is an artifact of the Finite Element procedure and is due solely to the singularities at the edges of the joint. Previous publication6 recommended that the values for strain energy density ΔW_i and ΔW_p values be determined by aver-
aging the strain energy density analysis results over all the elements at the solder interface. However, it was noted in Reference\(^{22}\) that for crack initiation life, \(N_i\), could be better predicted by using the maximum values strain energy density occurring over one thermal cycle. Further evaluation of absolute values was deemed appropriate, since the physical stress intensity factor at the corner of the solder joint could be captured by default with Finite Element model point singularities occurring at the joint corners. This approach was adopted in this study. For crack propagation life, \(N_p\), averaging of the strain energy density was still employed, since the defined failure mode involved all the elements along the cracked region of the solder joint. It should be noted that averaging values over the solder joint interface was also done successfully by Sauber and Seyyedi in Reference\(^{22}\). However, they chose to use strain range instead of strain energy density as achieved in this work.

A significant assumption was used in the application of Equations 2 and 3 which may effect the resulting predictions follows. These equations were originally developed specifically for 62Sn36Pb2Ag. Similar relationships were not available for the solder (10Sn88Pb2Ag) used in this study. It would likely be expected that the coefficients would differ for the non-eutectic solder used in this case since the metallurgical structure of the solid solution is not nearly homogeneous. In spite of this, Equations 2 and 3 were used in making the life predictions. More work is underway at Motorola to characterize the fatigue of this and other solders. The methodology, however, in making the life prediction remains unaltered.

To determine the propagation lifetime, a characteristic crack length was chosen on the basis of how it would effect the device function. Early package development work indicated that solder fatigue cracking would initiate and propagate most likely at the interface of the die and solder die attach (Figure 8). The higher strain energy range in joint provided substantiation to this hypothesis. When a crack forms and propagates, two device failure mechanism occur simultaneously. First, the reduction of conduction area results in significantly with die solder separation. Such failure modes are interrelated since one typically accompanies another.

![Fatigue Crack](image)

**Figure 8.** Die attach solder most susceptible to solder fatigue.

Throughout the thermal cycling reliability testing, \(V_f\) was monitored at intervals of thermal cycles. Early in the solder dispense process, development for final assembly yielded failures (Figure 8) that resulting in out-of-specifications \(V_f\) due to insufficient electrical contact between the die and the cathode heat sink. Based on the observations of failures, a characteristic crack length of half the die size was chosen (such as, 37/2 or 18.5 mil, 0.47 mm).

### 4.2. Life Prediction

Table 3 provides a summary of the life prediction results based on the -65°C to 150°C thermal cycle. It was found that the initiation life was predicted to be just over half of the crack propagation life. As of this writing, thermal cycling testing is ongoing at the Motorola, SPS Power Products Reliability Laboratory. Over two hundred assembled Powermite packages were submitted for the test. To date, all packages have successfully completed 3500 thermal cycles (-65°C to 150°C). The packages were tested for \(V_f\) at intervals of 500 cycles. It was found that all the packages met the specifications and, moreover, there was negligible drift in the \(V_f\) measurement. Lack of significant change in \(V_f\) indirectly indicates that the solder joints are intact.

Ten parts were pulled from the on-going testing at 3500 cycles and were depotted. Figure 9 shows the exposed cathode heat sink lead with the solder die attach still adhered to the lead for one of these (depotted) parts. The dark gray region in the solder is the cracked region. The cracked region is on the periphery of the solder joint. After the 3500 cycles, the crack growth was about 4 mil (0.1016 mm) on the joint side furthest from the cathode lead. This fact is consistent with the analysis results.

![Depotted Powermite Package](image)

**Figure 9.** De-potted powermite package after 3500 cycles.

<table>
<thead>
<tr>
<th>(\Delta W_i) (psi)</th>
<th>Initiation Life (cycles)</th>
<th>(\Delta W_p) (psi)</th>
<th>Propagation Life (cycles)</th>
<th>Total Life (cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>740</td>
<td>35</td>
<td>1310</td>
<td>2050</td>
</tr>
</tbody>
</table>

### 5. On-Going Fatigue Testing

As of this writing, thermal cycling testing is ongoing at the Motorola, SPS Power Products Reliability Laboratory. Over two hundred assembled Powermite packages were submitted for the test. To date, all packages have successfully completed 3500 thermal cycles (-65°C to 150°C). The packages were tested for \(V_f\) at intervals of 500 cycles. It was found that all the packages met the specifications and, moreover, there was negligible drift in the \(V_f\) measurement. Lack of significant change in \(V_f\) indirectly indicates that the solder joints are intact.

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6. Summary

Motorola has complete qualification of a new microminature Schottky package called the Powermite. The Powermite Schottky rectifier will be available soon in volume quantities and is slated for applications such as AC/DC and DC/DC converters, reverse battery protection.

Presented in this paper is a solder fatigue reliability model for microelectronic packages. The strengths of the methodology presented is an extension of the work already published. The reliability model is a function of the incremental strain energy density accumulated over the manufacturing processing and the thermal cycling. The deformation model allows for accurate representation of the deformation kinetics of the solder material. Most of the accumulated thermal mechanical induced strain energy occurs during manufacturing. It was found that the resulting solder life prediction (2050 cycles) is below what has been measured to date (>3500 cycles).

The modeling effort, as applied in this study, is not without its shortcomings. First and foremost, the Anand parameters and reliability life model is based on other materials than the solder systems used in the Powermite package. More work is underway at Motorola in generating empirical data for deformation and fatigue for other solder systems. The results of these efforts were not available at this writing. The methodology, however, in making the life prediction remains unaltered.

Nomenclature

\[ A \]  pre-exponential factor  
\[ N \]  total number of thermal cycles  
\[ N_i \]  crack initiation life  
\[ N_p \]  crack propagation life  
\[ Q/R \]  activation energy / universal gas const.  
\[ S_o \]  initial value of deformation resistance  
\[ \Delta W_i \]  plastic work increment for initiation  
\[ \Delta W_p \]  plastic work increment for propagation  
\[ a \]  strain rate sensitivity of hardening  
\[ a_c \]  characteristic crack length  
\[ da/dN \]  crack propagation rate  
\[ h_0 \]  hardening constant  
\[ s^\alpha \]  coefficient for deformation resistance  
\[ m \]  strain rate sensitivity of stress  
\[ n \]  deformation resistance value  
\[ \zeta \]  multiplier of stress

Acknowledgments

Moffit Othman of Motorola, Semiconductor Products, Seremban (SBN), Malaysia is acknowledged for creating the Powermite Finite Element model. The Motorola Power Products Reliability Laboratory and the Product Analysis Laboratory is acknowledged for the contribution in the reliability thermal cycle testing.

References

1. Powermite is registered trademark of Micro USPD, Inc., Watertown, Massachusetts.
five years, Mr. Fusaro has been active in the Electronic Packaging world. At Motorola, Semiconductor Products Sector, Mr. Fusaro managed the Power Products Division, Packaging and Technology Center. His work was focused on the deformation kinetics of solder and the subsequent life predictions associated with numerous techniques. Mr. Fusaro’s work has been documented in over 20 publications and articles. Currently, Mr. Fusaro is working at Amkor Electronics, Chandler Arizona where he manages a product group focusing on Ball Grid Array (BGA) Technologies. Mr. Fusaro is a member of IMAPS Society.

David Culbertson is a Technical Staff Engineer with Motorola Inc. Semiconductor Products Sector, located in Tempe, Arizona. Mr. Culbertson has been extensively focused on the design, development and implementation of new devices and packages to support the low profile, small outline needs of the wireless communications market. He has been in the semiconductor design and manufacturing arena for 30 years where he has successfully introduced a number of new packages in the automotive and the wireless semiconductor markets. Mr. Culbertson earned his B. S. Degree in Management, International and Production Operations, from Arizona State University. Mr. Culbertson has a number of published papers on Thermal and Stress Management of Semiconductor Devices. He co-authored articles presented at the International Symposium on Microelectronics, and Semi Terminal Semiconductor and Temperature Measurement Symposium. Mr. Culbertson has discussed and filed patents relating to internal lead frame or package designs.

About the authors

David Dougherty is with Motorola, Inc., Semiconductor Products Sector, Semiconductor Components Group located in Phoenix, Arizona. Mr. Dougherty has been primarily involved in new product development for the packaging of discrete components, multi-die packages, and multichip modules. His background is Mechanical Engineering and he specializes in package design analysis including thermal, structural, and reliability considerations for automotive, consumer, and wireless applications. Mr. Dougherty earned his Master of Science Degree in Mechanical Engineering from Purdue University in 1989 and his B. S. Degree from the University of Maryland in 1985. Mr. Dougherty has published numerous papers, holds one US patent, and is a registered Professional Engineer in the State of Arizona. Mr. Dougherty is a member of IMAPS Society.

Mr. James M. Fusaro earned his B.S. Degree in Aerospace Engineering from Arizona State University in 1985. In 1990, he earned his M.S. Degree in Mechanical Engineering from RPI. Mr. Fusaro began his Engineering career in the Aerospace Industry, where he spent the better part of nine years devoted to numerical simulations for application in the Thermal Mechanical Sciences. For the past