Mission Statement

CAVE is dedicated to working with industry in developing and implementing new technologies for the packaging and manufacturing of electronics, with special emphasis on the cost, harsh environment, and reliability requirements of the automotive, aerospace, military, computing, portable and other industries.

Message from Director

These are tough economic times, and there is greater a need to balance short term needs with long term strategic goals of technology advancement in preparation for the next cycle of products. CAVE is a NSF Industry University Cooperative Research Center (I/UCRC). The center provides an ideal forum in which academia and industry work in partnership on identification of key road blocks relevant to electronics in harsh environments and development of innovative technologies for enabling cost-effective solutions.

The center is focusing on pre-product space with a mix of higher-risk, high-return programs to complement the industry’s internal research and development efforts. In this newsletter, I have highlighted some of the recent scientific advancements made by CAVE researchers.

Prognostics has gained increased visibility with the efforts to transition from a schedule based maintenance to a condition based maintenance. Advancements in this area have the potential of providing significant cost savings simultaneously with assuring needs of high reliability in electronics systems functioning in harsh environments. CAVE researchers have been developing damage precursors based approaches for prognostication of electronics in harsh environments. A new approach has been developed for anomaly detection and fault mode classification of interconnect reliability in shock and vibration. Methods have also been developed for the interrogation of system state in electronic systems subjected to multiple thermal environments. The advancements are part of a larger prognostic health monitoring system in development at CAVE. You will find more information on the above mentioned advancements presented in the newsletter in greater detail. I encourage you to contact the center researchers in each case for further information.

On May 19, 2009, I attended the first Pb-Free Electronics Manhattan Project (PERM) meeting in Hunt Valley Maryland to present the reliability concerns related to leadfree packaging for defense applications. It was clear that significant gaps existed in knowledge related to harsh environment reliability of leadfree electronics. The component manufacturers have largely transitioned to or are completely transitioning to leadfree electronic parts. However, reliability in long-life electronic systems subjected to harsh environments and dormant storage is yet to be completely characterized. In the interim, there are several solutions and accompanying potential problems including but not limited to mixed alloys, re-balled leadfree parts and mixed assemblies. CAVE researchers have been investigating the constitutive and damage behavior in these assemblies. Experimental results show that thermal aging adversely effects reliability of several of the SnAgCu formulation alloys which have been widely adopted as the front runners for leadfree transition. An overview of our findings is available inside.

I am also glad to welcome Vortant Technologies and Advanced Thermal Technologies to the CAVE Industrial Membership. Our next technical review is on September 9-10, 2009 and I hope to see you all at the review. A preliminary listing of projects is attached inside.

Pradeep Lall
Thomas Walter Professor and Center Director
CAVE³ Review and Meetings

CAVE³ Consortium Fall Technical Review Meeting

The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE³) will hold its Fall Technical Review and Project Planning Meeting on September 9-10, 2009 in the Auburn University Hotel & Conference Center. All current members of the consortium are invited to attend. The agenda for this event is available at cave.auburn.edu under CAVE³ Reviews. The following projects will be presented at the meeting:

- Advanced Interconnect Systems and 3D-Packaging Architectures in Harsh Environments
- Prognostic Health Monitoring Methodologies for Damage Estimation in Leaded and Lead-Free Solder Alloys
- Models for Part Selection and Obsolescence Risk-Mitigation in Area-Array Packaging Architectures
- Integrated Design and Reliability Environment for Advanced Area-Array and Perimeter Devices
- Part Survivability Envelopes in Shock and Vibration for System-Level Integration Guides
- Leadfree Part Reliability, Crack Propagation and Life Prediction under Extreme Environments
- The Effects of Environmental Exposure on Underfill Behavior and Flip Chip Reliability
- Harsh Environment Reliability of Underfilled Area-Array Flip-Chip Devices
- Die Stresses and Failure Progression in Microprocessors
- Models for Underfill Stress-Strain and Failure Behavior with Aging Effects
- Theoretical and Experimental Investigation on Fretting Corrosion and Thermal Degradation for Hybrid and Electric Vehicles
- Complaint Pin/Press Fit Technology
- Model Simulation and Validation for Vibration-Induced Fretting Corrosion
- Vibration Based Interfaces for Information Transmission
- Growth of Sn Whiskers on Semiconductors and Insulators
- Growth of Sn Whiskers in O₂ Environments
- Microstructural and Mechanical Studies of SAC/Sn-37Pb Mixed Solders
- Aging Behavior of Next Generation Pb-Free Alloys
- Extreme Low Temperature Behavior of Solders
- Composition, Microstructure, and Reliability of Mixed Formulation Solder Joints
- Melting Point Behavior of Mixed-Formulation Solders
- Spreading Behavior of Mixed-Formulation Solders
- Reliability Test for Harsh Environmental Capacitors
- Harsh Environment Substrate Performance
- Module Overmolding for Harsh Environments
- Thermal Performance of Laminate to Aluminum Attachment Materials
- In-Situ Environmental Testing for Solder Joint Reliability Alternative Method (II)
- Systems Reliability of Leadfree for Harsh Environment Electronics

7th Annual SMTA-CAVE³ AIMS Harsh Environment Electronics Symposium

Conference Chair
John Evans, CAVE³, Auburn University

October 5-6, 2009
Town & Country Resort & Convention Center
San Diego, CA

Symposium Overview

This symposium will address the concerns related to harsh environment electronics and the challenges within the electronics community, with an added emphasis on military and space. It is intended to bring together the needs of end-users with the capabilities of the research community and the industrial supply base. Specifically, the symposium addresses the challenges of meeting expanding temperature ranges (-55C to +150C/+200C) with increased vibration, higher package density and longer reliability. Next generation requirements for automotive electronics are explored from the system level and potential supply-based solutions are presented. In addition, requirements and solutions for non-automotive vehicles and industrial electronics applications will be addressed.

Presentations will be given by the following companies:
Dow Corning Corporation, Jet Propulsion Laboratories, Rockwell Collins, Auburn University, Cookson Electronics, Indium Corporation, STABLCOR Inc., and more...

SPECIAL EVENTS

October 5, 11:45 a.m. - 1:00 p.m.

Keynote Address: Managing a Perfect Storm: Pb-Free Electronics Risks
Edward A. Morris
Director, Hardware and Manufacturing, Corporate Engineering and Technology, Lockheed Martin Corporation

The shift to leadfree electronics by global electronics components suppliers has become an unintended source of risk to aerospace and defense (A&D) products, particularly those operating in harsh environments. The change to Pb-free materials was prompted by an EU Directive banning certain hazardous substances, including Pb, in commercial electronics sold in the EU. Unfortunately, the solders and finishes replacing tin-lead (SnPb) in electronics can result in solder joints that are less reliable in operating and storage environments that have extreme thermal cycles and are less tolerant of shock and vibration.

Technical paper tracks

Tuesday's sessions will once again feature technical paper presentations. Papers will be written by companies such as Auburn University, Boeing Company, Indium Corporation and more. All technical papers will be included on the symposium proceedings and the SMTA International Conference proceedings.
CAVE³ Acquires Drop/Shock Test Capabilities
CAVE³ has recently acquired Lansmont’s model M23 shock system. This model incorporates JEDEC test specifications and can acquire shock loading from few G-level to as high as 30,000 G-level. The model can also perform materials impact evaluation (cushion testing) or artificial turf testing with platens and impact forms. The model 23 features an electronic hoist lifting system for easy table positioning and can be outfitted with a seismic reaction mass to isolate shock energy from transmitting to the surrounding laboratory space. The model 23 has the ability to test printed circuit boards weighing up to 35 lbs. It can generate half sine shock pulse.

CAVE³ Adds Semi-Automatic Assembly Line

Vertical Separation, Dual-Squeegee Stencil Printer
The Manncorp 5500 Dual-Squeegee Stencil Printer provides consistent stencil height and pressure throughout the print stroke and then separates the stencil from the PCB with a true vertical motion that simulates the performance of much more costly automatic equipment. This ergonomically unique design features side-to-side squeegee motion for maximum operator ease while printing single or double-sided boards up to 500 mm x 550 mm (20” x 22”).

Many surface mount assemblers consider vertical separation of the stencil from the PCB an essential process parameter for ultra-fine pitch solder paste printing. Because angular separation is inherent to most clamshell type stencil printers, lower cost, benchtop equipment is often overlooked in favor of automatic or semi-automatic equipment, even if volume doesn't warrant these more costly systems. The printer overcomes the drawback of angular separation.

MO-100 Split-Vision Placement System
The equipment is intended for mounting of BGA, CSP, flip-chip, and fine-pitch QFP Devices. The Manncorp MO-100 Split-Vision Placement System adds high-precision placement capability to CAVE³ existing automated surface mount assembly. The split-vision optics is capable of handling components as large as 70 mm x 70 mm, provides simultaneous, superimposed views of the component leads and the PCB pads on its high-definition LCD display.

Ultra-fine adjustments for the X-, Y-, and angular-axes permit easy and accurate lead-to-pad alignment and precision-ground, Z-axis guide rails allow smooth and gentle lowering of the component to the PCB. By providing a low-cost, stand-alone solution for placement of hard-to-handle components that are typically used at lower quantities than discrete and SO devices, the extremely versatile MO-100 is the ideal adjunct to other automatic and semi-automatic pick-and-place equipment.

X-REFLOW306 LF Full Convection, Bench Top, Batch oven with Nitrogen Connections
The X-REFLOW is a high performance reflow batch oven designed for leadfree reflow, heat-resistant testing and small lot production. With its large back light LCD display the setting of the temperature and time or the operation, can be easily checked by numerical value or graph.

The unit has several features, which enhance operation.
- Full convection heating with independent control of front and rear heaters, which enables hot air temperature and time settings in five zones and pre-setting of various profiles for different PCB’s.
- Large inspection window allows for monitoring soldering process during operation (inspection can be done, if needed using a microscope or camera system). Microprocessor based control uses closed-loop monitoring to ensure absolute repeatability of the temperature profiles and has the memory to store 255 profiles.
- The large backlight display shows either the specific temperatures and times or a graph of temperature versus time in real time. The nitrogen gas inlet is standard and the oven can be used for soldering in nitrogen environment without requirement for any additional hardware.
Life Prediction of Leadfree Electronics in Shock-Impact

In the current study, Relative damage-index based on the leadfree interconnect transient strain history from digital image correlation, explicit finite-elements, cohesive-zone elements, and component’s survivability envelope has been developed for life-prediction of two-leadfree electronic alloy systems. Solder alloy system studied include Sn1Ag0.5Cu, and 96.5Sn3.5Ag. Transient strains during the shock-impact have been measured using digital image correlation in conjunction with high-speed cameras operating at 50,000 fps. Both the board strains and the package strains have been measured in a variety of drop orientations including JEDEC horizontal drop orientation, vertical drop orientation and intermediate drop orientations.

In addition, the effect of sequential stresses of thermal aging and shock impact on the failure mechanisms has also been studied. The thermal aging condition used for the study includes 125°C for 100 hrs. Velocity data from digital image correlation has been used to drive the attachment degrees of freedom of the submodel and extract transient interconnect strain history from digital image correlation, (see Figure 1). Explicit finite-element sub-modeling has been correlated with experimental results. Velocity data from digital image correlation has been used to drive the attachment degrees of freedom of the submodel and extract transient interconnect strain histories (see Figure 1). Explicit finite-element sub-modeling has been correlated with the full-field strain in various locations, orientations, on both the package and the board-side. The survivability of the leadfree interconnections under sequential loading (thermal aging and shock-impact) from simulation has been compared with pristine circuit assemblies subjected to shock-impact. Sequential loading changes the failure modes and decreases the drop reliability as compared to the room temperature experimental results. Damage index based survivability envelope is intended for component integration to ensure reliability in harsh environments.

Fault-Mode Classification for Health Monitoring of Electronics Subjected to Drop and Shock

Failures in electronics subjected to shock and vibration are typically diagnosed using the built-in self test (BIST) or using continuity monitoring of daisy-chained packages. The BIST which is extensively used for diagnostics or identification of failure is focused on reactive failure detection and provides limited insight into reliability and residual life. This study evaluates a new technique has been developed for health monitoring and failure mode classification based on measured damage pre-cursors. A feature extraction technique in the joint-time frequency domain has been developed along with pattern classifiers for fault diagnosis of electronics at product-level. The Karhunen Loève transform (KLT) has been used for feature reduction and de-correlation of the feature vectors for fault mode classification in electronic assemblies. Euclidean, and Mahalanobis, and Bayesian distance classifiers based on joint-time frequency analysis, have been used for classification of the resulting feature space. Previously, the authors have developed damage precursors based on time and spectral techniques for health monitoring of electronics without reliance on continuity data from daisy-chained packages. Previously, Statistical Pattern Recognition techniques based on wavelet packet energy decomposition have been studied by authors for quantification of shock damage in electronic assemblies, and auto-regressive moving average, and time-frequency techniques have been investigated for system identification, condition monitoring, and fault detection and diagnosis in electronic systems. However, identification of specific failure modes was not possible.

Research Highlights

**Shock-Impact**

The methodology addresses the need for life prediction of new lead-free alloy-systems under shock and vibration, which is largely beyond the state of art. Three failure modes have been predicted including interfacial failure at the copper-solder interface, solder-PCB interface, and the solder joint failure. Explicit non-linear finite element models with cohesive-zone elements have been developed and correlated with experimental results. Velocity data from digital image correlation has been used to drive the attachment degrees of freedom of the submodel and extract transient interconnect strain histories (see Figure 1). Explicit finite-element sub-modeling has been correlated with the full-field strain in various locations, orientations, on both the package and the board-side. The survivability of the leadfree interconnections under sequential loading (thermal aging and shock-impact) from simulation has been compared with pristine circuit assemblies subjected to shock-impact. Sequential loading changes the failure modes and decreases the drop reliability as compared to the room temperature experimental results. Damage index based survivability envelope is intended for component integration to ensure reliability in harsh environments.

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**Figure 1: Node Based sub modeling technique**

**Figure 2: Overlap of Simulation and Experimental feature Spaces.**

Current study shows various fault modes such as solder inter-connect failure, inter-connect missing, chip delamination chip cracking etc in various packaging architectures have been classified using clustering of feature vectors based on the KLT approach. The KLT de-correlates the feature space and identifies dominant directions to describe the space, eliminating directions that encode little useful information about the features. The clustered damage precursors have been correlated with underlying damage (see Figure 2). Several chip-scale packages have been studied; with leadfree second-level interconnects including SAC105, SAC305 alloys. Transient strain has been measured during the drop event using digital image correlation and high-speed cameras operating at 100,000 fps. Continuity has been monitored simultaneously for failure identification. Fault-mode classification has been done using KLT and joint-time-frequency analysis of the experimental data. In addition, explicit finite element models have been developed and various kinds of failure modes have been simulated such as solder ball cracking, trace fracture, package falloff and solder ball failure. Models using cohesive elements present at the solder joint-copper pad interface at both the PCB and package side have also been created to study the traction-separation behavior of solder. Fault modes predicted by simulation based pre-cursors have been correlated with those from experimental data.
ARMA based Prognostics and Condition Monitoring of Electronics

Leading indicators based approach has been developed for prognostics and health monitoring of electronic systems. The approach focuses on the pre-failure space and methodologies for quantification of damage progression and residual life in electronic equipment subjected to shock and vibration loads using the dynamic response of the electronic equipment. Traditional health monitoring methodologies have relied on reactive methods of failure detection often providing little or no insight into the remaining useful life of the system. The proposed techniques have a wide applicability to electronic systems requiring high reliability. Operational readiness and high-system availability are critical for reduction of uncertainty in mission-critical electronic systems. Examples include aerospace-electronic systems which usually face a very harsh environment, requiring them to survive the high strain rates, e.g. during launch and re-entry and thermal environments including extreme low and high temperatures and implantable biological systems such as pacemakers and defibrillators.

Prognostic indicators can trigger preventive maintenance based on need instead of “fear-of-failure”. Auto-regressive (AR), wavelet packet energy decomposition, and time-frequency (TFA) techniques have been investigated for system identification, condition monitoring, and fault detection and diagnosis in electronic systems. The test vehicle is subjected to repeated proof-load events of a wide frequency range. In this approach, the known auto correlation sequence of the feature vectors, is extrapolated to estimate auto correlation sequence at unknown lags. One of the main advantages of the AR technique is that it is primarily a signal based technique. Reduced reliance on system analysis helps avoid errors which otherwise may render the process of fault detection and diagnosis quite complex and dependent on the skills of the analyst. Results of the present study show that the AR and TFA based health monitoring techniques are feasible for fault detection and damage-assessment in electronic units (see Figure 3).

Figure 3: Correlation between the measured and ARMA prediction of Mode-1 PSD evolution with damage progression

Explicit finite element models have been developed and various kinds of failure modes have been simulated such as solder ball cracking, package falloff and solder ball failure.

Prognostication of Latent Damage and Residual Life in Leadfree Electronics

Electronic assemblies deployed in harsh environments may be subjected to multiple thermal environments during the use-life of the equipment. Often the equipment may not have any macro-indicators of damage such as cracks or delamination. Quantification of thermal environments during use-life is often not feasible because of the data-capture and storage requirements, and the overhead on core-system functionality. There is need for tools and techniques to quantify damage in deployed systems in absence of macro-indicators of damage without knowledge of prior stress history. The presented PHM framework is targeted towards high reliability applications such as avionic and space systems. In this experiment, Sn3.0Ag0.5Cu alloy packages have been subjected to multiple thermal cycling environments including -55 to 125°C and 0 to 100°C. Assemblies investigated include area-array packages soldered on FR4 printed circuit cards. The methodology involves the use of condition monitoring devices, for gathering data on damage precursors at periodic intervals. Damage-state interrogation technique has been developed based on the Levenberg-Marquardt Algorithm in conjunction with the microstructural damage evolution proxies.

Figure 4: Life vs Damage Curve for Multiple Thermal Environments

The developed technique is applicable to electronic assemblies which have been deployed on one thermal environment, then withdrawn from service and targeted for redeployment in a different thermal environment (see Figure 4). Test cases have been presented to demonstrate the viability of the technique for assessment of prior damage, operational readiness and residual life for assemblies exposed to multiple thermo-mechanical environments. Prognosticated prior damage and the residual life show good correlation with experimental data, demonstrating the validity of the presented technique for multiple thermo-mechanical environments.
**Resistance Spectroscopy-based Condition Monitoring for Prognostication Under Shock-Impact**

Traditionally, resistance spectroscopy measurements have been used during thermal cycling tests to monitor damage progression due to thermo-mechanical stresses. The high frequency characteristics, and system transfer function based on resistance spectroscopy measurements have been correlated with the damage progression in electronics during shock and vibration. Recently, an experimental study has been conducted to detect solder joint damage as shown in Figure 1. Second level interconnect technologies examined include copper-reinforced solder column, SAC305 solder ball, and 90Pb10Sn high-lead solder ball. Assemblies have been subjected to 1500g, 0.5 ms pulse [JESD-B211]. Continuity has been monitored in-situ during the shock test for identification of part-failure. Resistance spectroscopy based damage pre-cursors have been correlated with the optically measured transient strain based feature vectors. High speed cameras have been used to capture the transient strain histories during shock-impact.

![Figure 5: Leading indicator of failure (blue dashed line) plotted against the resistance of a package (solid green line) during a vibration test.](image)

Statistical pattern recognition techniques have been used to identify damage initiation and progression and determine the statistical significance in variance between healthy and damaged assemblies. Models for healthy and damaged packages have been developed based on package characteristics. Experimental data shows that high-frequency characteristics and system-transfer characteristics based on resistance spectroscopy measurements can be used for condition-monitoring, damage initiation and progression in electronic systems (see Figure 5).

**Isothermal Aging Induced Evolution of the Material Behavior of Underfill Encapsulants**

Microelectronic encapsulants exhibit evolving properties that change significantly with environmental exposures such as isothermal aging and thermal cycling. Such aging effects are exacerbated at higher temperatures typical of thermal cycling qualification tests for harsh environment electronic packaging. In this work, the material behavior changes occurring in flip chip underfill encapsulants (silica filled epoxies) have been characterized for isothermal aging at four different temperatures that are below, near, and above the Tg of the material. A microscale tension-torsion testing machine has been used to evaluate the uniaxial tensile stress-strain and creep behaviors of the underfill material at several temperatures, after various durations of environmental exposure.

![Figure 6: Stress-Strain Curves for Aged and Non-Aged Samples (T = 100 deg C)](image)

A novel method has been developed to fabricate underfill uni-axial test specimens so that they accurately reflect the encapsulant layer present in flip chip assemblies. Using the developed specimen preparation procedure, samples were prepared and isothermal aged for up to 10 months at 80, 100, 125, and 150°C. Stress-strain and creep tests were then performed on both non-aged and aged samples at several different temperatures (25, 50, 75, 100, 125, and 150°C). The changes in mechanical behavior were recorded for the various aging temperatures and durations of isothermal exposure (see Figure 6). Empirical models have been developed to predict the evolution of the material properties (modulus, strength) and the creep strain rate as a function of temperature, aging time, and aging temperature.
Analysis of Mixed Formulation Solder Joints

The transition from tin-lead to lead free soldering in the electronics manufacturing industry has been in progress for the past 10 years. In the interim period before lead free assemblies are uniformly accepted, mixed formulation solder joints are becoming commonplace in electronic assemblies. For example, area array components (BGA/CSP) are frequently available only with lead free Sn-Ag-Cu (SAC) solder balls. Such parts are often assembled to printed circuit boards using traditional 63Sn-37Pb solder paste. The resulting solder joints contain unusual quaternary alloys of Sn, Ag, Cu, and Pb. In addition, the alloy composition can vary across the solder joint based on the paste to ball solder volumes and the reflow profile utilized.

The mechanical and physical properties of such Sn-Ag-Cu-Pb alloys have not been explored extensively in the literature. In addition, the reliability of mixed formulation solder joints is poorly understood. This work explores the physical properties and mechanical behavior of mixed formulation solder materials. Seven different mixture ratios of 63Sn-37Pb and SAC305 solder materials have been formed, which include five carefully controlled mixtures of the two solder alloys (by weight percentage) and the two extreme cases (pure Sn-Pb and pure SAC). For the various percentage mixtures, the melting point, pasty range, stress-strain curves, mechanical properties (modulus, strength), and creep curves have been characterized (see Figure 7). The variations of the mechanical properties and creep rates with aging at room temperature (25°C) and elevated temperature (100°C) have also been measured. The microstructures realized with the various mixtures have been found and correlated to the mechanical measurements and microstructures found in actual mixed formulation BGA solder joints. The results for the mechanical and physical properties show a very complicated dependence on the mixture ratio.

The Effects of SAC Alloy Composition on Aging Resistance and Reliability

The microstructure, mechanical response, and failure behavior of lead free solder joints in electronic assemblies are constantly evolving when exposed to isothermal aging and/or thermal cycling environments. Prior work on aging effects demonstrated that the observed material behavior variations of Sn-Ag-Cu (SAC) lead free solders during room temperature aging (25°C) and elevated temperature aging (125°C) were unexpectedly large and universally detrimental to reliability. Such effects for lead free solder materials are especially important for the harsh applications environments present in high performance computing and in automotive, aerospace, and defense applications. However, there has been little work in the literature, and the work that has been done has concentrated on the degradation of solder ball shear strength (e.g. Dage Shear Tester). Current finite element models for solder joint reliability during thermal cycling accelerated life testing are based on traditional solder constitutive and failure models that do not evolve with material aging. Thus, there will be significant errors in the calculations with the new lead free SAC alloys that illustrate dramatic aging phenomena. Current work shows the extension of previous studies to include a full test matrix of aging temperatures and solder alloys.

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A Study of Vibration-induced Fretting Corrosion

It is generally recognized that vibration-induced fretting degradation can be a major problem for connector systems used in vehicle electronics. At present much of the evaluation of fretting propensity for particular connector designs and the influence of variations in those designs on fretting performance has been conducted through exhaustive experimental testing, which requires a major commitment of time and resources. Therefore, simulation-based methods would be of great value to those working on connector design and applications. In this regards, a study of vibration-induced fretting degradation was conducted for a sample connector system. Initially, a single blade/receptacle connector pair was studied. A model was developed and experimentally validated.

This work was extended with detailed 3-D and 2-D simulation models (Figure 9) that have been developed for a specific connector that includes wiring properties, contact interface characteristics, and housing dynamics. The results from these simulation models have been compared with the experimental results for the same connector and good correlation has been obtained for both models. It was noted that the 2-D model, while less precise, is much more computationally efficient and practical for extensive simulation studies.

Alternative Method for In-Situ Environmental Testing for Solder Joint Reliability

The current study provides an improved in-situ environmental testing system for solder joint reliability. The system can monitor the reliability of up to 2048 solder joint resistors and detect their resistance change when they are in a harsh environmental chamber. A matrix design is adopted for these resistors’ connection. Only 96 wires are needed to connect the testing system and these 2048 solder joint resistors, which pass through the hole on the wall of environmental chamber (Figure 10). The hardware uses multiplexers and digital I/Os, and the software programs are implemented in LabVIEW. Compared with previous designs, this new system doesn’t only increase the measurement capability, but also brings on a huge saving on hardware cost.

Auger Electron Spectroscopic (AES) Measurements on High Aspect Ratio Tin Whiskers

With the implementation of RoHS directives regarding Pb-free electronics, pure tin (Sn) films and board finishes offer potentially serious reliability issues due to Sn whisker formation. A key aspect of Sn whiskers is their material composition, which has been assumed pure crystalline Sn since 1951. Due to the submicron width (~ 0.25 μm) of high aspect ratio whiskers, it has been difficult for even state-of-the-art materials techniques to provide clear, unambiguous data on Sn whiskers and, in particular, the surfaces of Sn whiskers.

In this study, high resolution Auger electron spectroscopy (AES) has been used to determine both the surface and bulk composition of high aspect ratio Sn whiskers (Figure 11). The whiskers were grown from intrinsically stressed thin films (~ 6000 Å) of Sn on brass, deposited using cylindrical magnetron sputtering techniques. Results show that the whiskers are 100% Sn at the whisker base, shaft, tip, and up to a substantial depth into the whisker bulk. No evidence of pull-up from the brass substrate or surface contaminants is observed in the whiskers. A remarkable aspect of the growth is that high aspect ratio whiskers ~ 10-100 μm in length are grown from a ~ 0.6 μm thin film of Sn on brass.
Thermal Performance Of Laminate-To-Aluminum Attachment Materials

A non-destructive method was used to determine the effects of thermal cycling on the thermal performance of a PCB attached to an aluminum substrate with a thermal adhesive. This method allows for a comparison of the thermal performance of various TIMs in an industrial application.

Testing was done on FR4 and flex boards, both with and without overmolding, attached using pressure sensitive adhesive (PSA) and an alternative adhesive. Baseline measurements were taken, then the boards were cycled from -40 to 125°C on a 90-minute cycle with 15-minute dwells at the target temperatures. It was found that both adhesives showed a decrease in thermal resistance, possibly due to curing, and that delamination occurred at 17 out of 35 locations with the alternative adhesive within the first 1000 cycles while no delamination occurred with the PSA.

While the method used is not capable of detecting the presence of delamination in overmolded boards, it was seen that the thermal conductivity of the PSA adhesive showed similar improvements due to curing with the overmolding as it did without the overmolding (Figure 12). It was also found that severe cracking occurred in overmolding A after 250 cycles while no cracking occurred in overmolding B after 1000 cycles.

Impact Of Component Termination On Conductive Adhesive Reliability

Conductive adhesives have been used for many applications as alternatives for tin lead solder and for many applications where solder is not desirable. Often passive devices are the most critical components related to long-term reliability for harsh environment electronics. This study investigates the impact of the termination of these components on long-term reliability of electrically conductive materials. Figure 13 shows the failure modes on pads due to prolonged exposure to extreme environment.

The study considers six termination options on three different component body sizes. Two conductive adhesive materials are studied using a gold plated laminate circuit board. Contact resistance and component shear strength are measured under thermal cycling conditions from -40°C to +150°C. This test investigated these material conditions over the course of 2000 thermal cycles.

Module Overmolding

In an attempt to increase thermal performance, long-term reliability, and systems size reductions, many manufacturers are investigating module level overmolding for harsh environment electronics. A representative assembly is shown in Figure 14. CAVE3 researchers are currently evaluating many material, component and substrate options for these applications.

The work focuses on the component reliability, manufacturability, and thermal performance for a wide variety of materials. CAVE3 is also working to quantify the acceleration factors in molded assemblies to correlate the accelerated test life to field environments. Current applications are considering temperature ranges from -55C to +150C.
Announcements

**Lall, Suhling give Technical Keynotes at EuroSimE in Delft, Netherlands, April 27-29, 2009**

Drs. Pradeep Lall and Jeffrey C. Suhling gave invited technical keynotes at the 10th IEEE European Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro/Nanoelectronics and Systems. Topics included prognostics and condition monitoring of electronics, and application of stress testing test chips to area array packaging respectively.

**Dr. Pradeep Lall is Elected an ASME Fellow (American Society of Mechanical Engineers)**

Dr. Lall is the Thomas Walter Professor with the Department of Mechanical Engineering and Director of the NSF Center for Advanced Vehicle Electronics at Auburn University. He is author and co-author of 2-books, 11-book chapters, and over 225 journal and conference papers in the field of electronic packaging with emphasis on prognostics, diagnostics, design, modeling and predictive techniques. Topics include thermo-mechanics, reliability and life-prediction of electronics failure-mechanisms, prognostics and structural health monitoring of electronic structures, transient dynamics of microcircuits and MEMS in shock and vibration.

**Dr. Jeff Suhling is Elected an ASME Fellow (American Society of Mechanical Engineers)**

Dr. Suhling is the Quina Distinguished Professor and Chair, with the Department of Mechanical Engineering. He has worked actively in the area of electronic packaging for over twenty years specializing in the application of silicon stress sensors and test chips, as well as the characterization of packaging materials. His general research areas include experimental mechanics, solid mechanics, composite materials, electronic packaging, silicon sensors, and solder joint reliability.

**CAVE3 Researchers Win Best Paper Award – SMTAI**


**Roy Knight receives Outstanding ME Faculty-Member Award**

Dr. Roy W. Knight, faculty member in the Department of Mechanical Engineering, Auburn University, received the Outstanding Mechanical Engineering faculty-member award at the Samuel Ginn College of Engineering Faculty/Student Awards Reception in March 2009. Dr. Knight's areas of teaching and research include Thermal Sciences and Thermal Issues in Electronics Packaging.

**CAVE3 Student selected for Hutchins Grant**

Zhaozhii Li, a doctoral student advised by Dr. John Evans in Auburn University's Department of Industrial and Systems Engineering, has been chosen as a recipient of the 2009 Charles Hutchins Educational Grant. The $5,000 award will be presented to Li at the Surface Mount Technology Association (SMTA) annual meeting in October.

**Dr. Jinchun Gao Joins CAVE3**

Dr. Jinchun Gao, from Beijing Tel & Comm. University, China joined CAVE recently. Her research interest includes Environmental effects on electrical contact reliability, mechanism and analysis of electrical contact failure, characteristics and effects of dust particles on electrical contacts.

**Advanced Thermal Technologies and Vortant Technologies have joined CAVE3**

Advanced Thermal Technologies based in Upton, MA and Vortant Technologies based in Weaverville, NC have joined CAVE3.

**CAVE3 Faculty authored Book Publications**

- “Mechanical Design of Electronic Systems”, Dally, James; Lall, Pradeep; and Suhling, Jeffrey. This book has been written for engineers to serve as a first text on the packaging of electronic systems. The engineering student should have completed fundamental courses in the engineering sciences, thermal sciences and materials as pre-requisites. The practicing professional will probably be at the early stages of his or her career and be more concerned with the technical details of the design rather than the business strategy of a product line. Publisher: College House Enterprises, LLC. Copyright Year : 2008, Number of Pages : 664, ISBN-10: 0976241331, ISBN-13: 978-0976241331

**Book Chapters**


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