AUBURN UNIVERSITY
SAMUEL GINN
COLLEGE OF ENGINEERING

Fall 2014

cave^3 News

NSF-CAVE3 Electronics Research Center
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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

Military and defense systems increasingly depend on the use of consumer electronics for sustained operation for extended periods of time in extreme environments. Consumer electronics technologies are often designed for office benign environments with design lifetimes significantly lower than the 20-40 year operational life of typical military and defense systems. Consumer electronics is driven by product volumes and lower labor costs which are not offered by the military and defense applications. Design lifetimes, mission criticality, survivability expectations in extreme environments and design attributes have a minimal overlap with military and defense applications. Furthermore, consumer electronics may use materials and manufacturing processes incompatible with existing infrastructure for defense systems. Electronics manufacturing has migrated from the US to Far East destinations either in China, Taiwan, Malaysia, Indonesia, South Korea, and Japan amongst other locations. The lack of manufacturing expertise in the United States limits the use of latest consumer technologies in advanced weapon systems and impacts the sustainment of the systems in the long-term. In July 2014, a team led by Auburn University responded to an RFI proposing the focus of an Institute of Manufacturing Innovation to be on the topic of electronics packaging and reliability. The team consists of (in alphabetic order): Auburn University, Binghamton University, Purdue University, Stanford University, University of Maryland, and the University of Texas at Arlington. The intent is to develop a national network of manufacturing innovation in the area of electronic packaging and reliability by building around the regional hubs of excellence such as CAVE3 at Auburn University, CALCE at University of Maryland, IEEC at Binghamton University, and UTARI at the University of Texas at Arlington. Investment in the technologies for military and defense applications may catalyze additional opportunities for commercial breakthroughs. An IMI on the topic of electronic packaging and reliability for extreme environments may trigger the development of technologies which will have applications in durable high volume consumer goods which require operation in extreme environments albeit at a lower level of mission criticality such as electric vehicles which are not mainstream right now. A manufacturing ecosystem for extreme environment electronics will enable the creation of new manufacturing jobs and spur economic development.

- Pradeep Lall, T. Walter Professor and Director

Professor Lall Honored with IEEE-CPMT Exceptional Technical Achievement Award

Pradeep Lall, the Thomas Walter Professor in the Department of Mechanical Engineering and director of Auburn's National Science Foundation Center for Advanced Vehicle and Extreme Environment Electronics, has been honored with the Exceptional Technical Achievement Award from the Institute of Electrical and Electronics Engineers Components, Packaging, and Manufacturing Technology Society. Lall received the award for his contributions to the field of electronics reliability and manufacturing. Prof. Lall's work which has been presented through technical papers, book chapters, and short courses, is a subset of a long and distinguished list of publications which spans 2 books, 14 book chapters and over 400 technical papers in journals and conferences. Lall is a fellow of the IEEE, serves on the IEEE Reliability Society AdCom, and is the IEEE Reliability Society representative on the IEEE-USA Government Relations Council for R&D Policy.

CAVE^3 Consortium Spring-2015 Technical Review Meeting

The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE^3) will hold its Spring Technical Review and Project Planning Meeting on March 5-6, 2015 in Auburn University Wiggins Hall. All current members of the Consortium are invited to attend. The agenda for this event is available at cave.auburn.edu under CAVE^3 Reviews. The following projects will be presented at the meeting:

- Acceleration Factors and Life Prediction Models for on-chip and off-chip Failure Mechanisms
- Advanced Interconnect Systems and 3D-Packaging Architectures in Harsh Environments
- Prognostic Health Monitoring Methodologies for Damage Estimation in Leaded and Lead-Free Solder Alloys
- PHM for Field-Deployed Electronics Subjected to Multiple Thermal Environments
- Leadfree Part Reliability, Crack Propagation and Life Prediction under Extreme Environments
- The Effects of Environmental Exposure on Underfill Behavior and Flip Chip Reliability
- Models for Underfill Stress-Strain and Failure Behavior with Aging Effects
- Insitu Die Stress Measurements in Flip Chip Packaging
- Modeling and Material Characterization for Flip Chip Packaging
- 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
- 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
- QFP Reliability on Powered and Non-powered Thermal Cycle Environment
- Harsh Environment Substrate Performance
- Module Overmolding for Harsh Environments
- Systems Reliability of Lead Free for Harsh Environment Electronics

A block of rooms has been reserved for Review attendees at the preferred group rate. Room block will expire on February 15, 2015.

Contact Information:
Auburn University Hotel & Conference Center
241 South College Street
Call: (334) 821-8200

SPECIAL EVENTS

2014 IEEE International Conference on Prognostics and Health Management

June 22-25, 2015
Austin, TX

General Chair
Prof. Pradeep Lall

The 6th Annual IEEE Reliability Society PHM conference will be held June 22-25 at in Austin, TX. The conference will bring together persons from Industry and Academia, including engineers, scientists and managers from around the world to share and discuss the state of the art, state of practice, and future of Prognostics and Health Management. The conference includes Tutorials, Panel Sessions, and Papers that address the wide-ranging, interdisciplinary topics related to PHM technology and application. There will be a special working session on the in-process development of a PHM Standard. There will be a special session with presentations from the most successful entries in the conference PHM Challenge. Although the deadline for abstracts is past, the conference is accepting submission of full papers through the end of January. Papers will be reviewed, and those meeting the publication criteria, selected and presented at the conference will be published by the IEEE. Additional information about the conference, the challenge, and submitting papers is available on the conference web site at: phmconf.org.

Harsh Environment Electronics Symposium at the SMTA International 2014

Conference: Sep. 28—Oct. 2, 2014
Donald Stephens Convention Center, Rosemont, IL

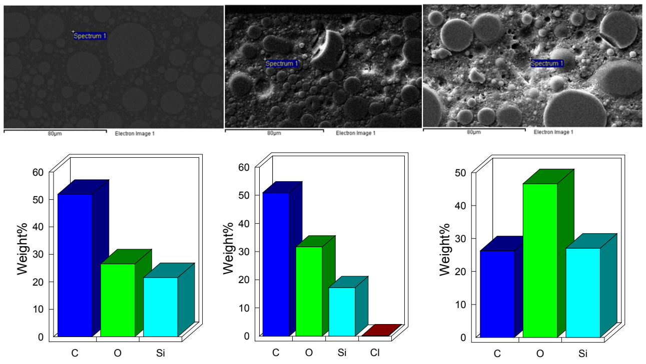
The SMTA and CAVE3 at Auburn University will hold the 11th AIMS (Automotive, Industrial, Military and Space) Harsh Environment Electronics Symposium in Rosemont, Illinois on Sept 29-30, 2014. The symposium will be collocated with the SMTA Conference and consist of technical sessions spanning 1.5 days. Dr. Pradeep Lall, Dr. John Evans, and Dr. Robert Kinyanjui, are Symposium Chairs. The symposium will focus on harsh environments with an emphasis on automotive, military and space applications. Specific subject areas include, but are not limited to:

► Alternative Energy (including, wind, water transportation, battery)
► Components and Component Reliability
► Corrosion
► Extreme Environmental Applications
► Lead-Free Issues for Harsh Environments
► Substrate Surface Finishes for Harsh Environment Applications
► Thermal Management
► Tin Whiskers

Research Highlights

Development of Package for Sustained Operation at 200°C

Plastic encapsulated microelectronics (PEMs) has found wide spread applications in automotive environments for varied roles. Transition to hybrid electric vehicles and fully electric vehicles has increased the trend towards greater integration of electronics in automotive under hood environments. Electronics in such applications may be mounted directly on engine and on transmission. Electronics under hood may be subjected to temperatures in neighborhood of 200°C. Commercially available PEMs are able to operate in the neighborhood of 175°C. However, sustained operation at temperatures of 200°C or higher is beyond the state of art. Materials and processing techniques needed for sustained high temperature operation for 10 years and 100,000 miles of vehicle operation are yet unknown. There is need for studies for understanding the failure mechanisms of PEMs at sustained high temperature. In this project, a new approach is discussed to study physical and chemical stability of molding compound when it is subjected to very high temperature for prolonged duration. Four mold compound candidates were selected for test purpose. Mold compound-A is a high temperature epoxy molding compound capable of low warpage, and excellent reflow crack resistance. Mold compound-B is a higher temperature version of the mold compound–A. Mold compound-C is a multi-aromatic epoxy with multi-aromatic hardener and low-alpha filler with a filler content of 85%. Mold compound-D is a silicon encapsulation material capable of high electrical resistivity, high thermal and mechanical stability. They were subjected to thermal aging at 200°C and 250°C, for 5000 hours. For degradation study, bulk mold compound specimens as well as 20 pin SOIC devices, encapsulated with MC candidates were used. Test vehicle was bonded with gold wires, and Pd coated Al pad. For bulk mold compound samples, weight loss test, DMA, FTIR, XPS tests were performed at fixed time intervals. To study integrity of SOIC devices, resistance spectroscopy, x-ray inspection and current leakage tests were selected. Another set was subjected to 120 hours of aging at 130°C/100%RH condition to check leakage current. Performance of MC candidates at high temperature was evaluated using all these tests. Sensitivity of each test towards detecting degradation of EMC's is also discussed and most effective tests are suggested.



(a) (b) (c)

Figure 1 EDS Analysis of EMC Candidate-A – (a) Time 0 (b) Intermediate Oxidation (c) complete Oxidation

X-Ray µCT for Defect Detection in Fine-Pitch Electronics Manufacturing

In this project MATLAB codes have been developed for the visualization of defects in second level interconnects during assembly of fine pitch electronics. The algorithms have been meshed with the µ CT commercial platform to analyze a wide array of common manufacturing defects. The industry is going through a transition in material sets for second level interconnects including adoption of leadfree solders. High-rel systems may often have a mix of components with different solder alloys in the printed circuit assemblies including both leaded and leadfree solders because some original leaded components may only be available in leadfree configurations.

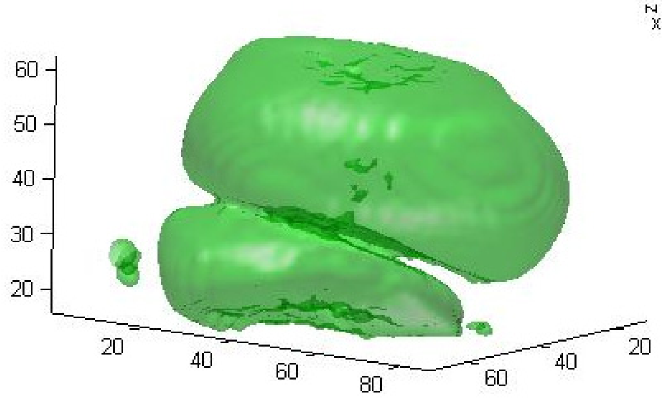


Figure 2 – 3D µCT Rendering of Head and Pillow Defect

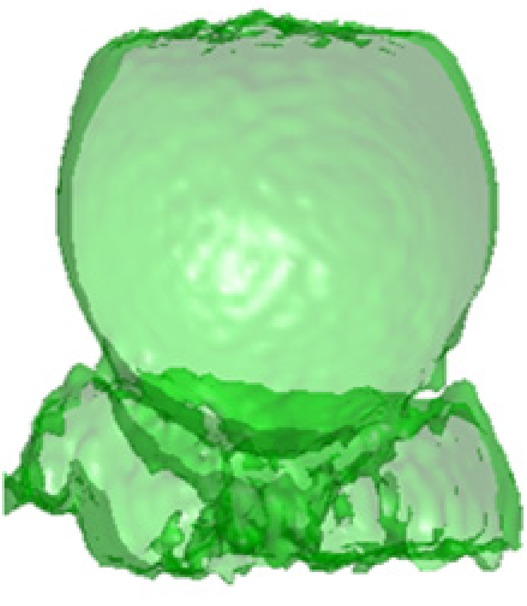


Figure 3: 3D Rendered solder ball lift.

The potential of x-ray micro-computed tomography (µCT) to fulfill the need for non-destructive three dimensional imaging of electronic assemblies has been evaluated. A number of defect seeded assemblies have been used for detection of a number of common solder interconnect defects and failure modes. In addition, the ability of the x-ray µCT for examination of complete products has been examined. Three-dimensional rendered versions of the board assemblies have been constructed for visualization of the defects and failure modes. Void sizes have been measured using Volume Graphics reconstruction and Matlab modules. In each case, the assemblies have been cross-sectioned after imaging by x-ray µCT to ascertain the morphology of the defect or failure mode using optical imaging. Results indicate that x-ray µCT is capable of providing high resolution imaging of the common defect types and failure modes in electronic assemblies and has potential for risk mitigation in sustainment of long-life high-rel systems.

Prognostic Indicators for Defect Detection in Copper-Aluminum Wire Bonds

In this project, a new approach has been developed to identify the occurrence of impending apparently-random defect fall-outs and premature failures observed in the Cu-Al wirebond system. The use of intermetallic thickness, composition and corrosion as a leading indicator of failure for assessment of remaining useful life for Cu-Al wirebond interconnects has been studied under exposure to high temperature and temperature-humidity. Gold wire bonding has been widely used as first-level interconnect in semiconductor packaging. The increase in the gold price has motivated the industry search for alternative to the gold wire used in wire bonding and the transition to copper wire bonding technology. Potential advantages of transition to Cu-Al wire bond system includes low cost of copper wire, lower thermal resistivity, lower electrical resistivity, higher deformation strength, damage during ultrasonic squeeze, and stability compared to gold wire. However, the transition to the copper wire brings along some trade-offs including poor corrosion resistance, narrow process window, higher hardness, and potential for cratering.

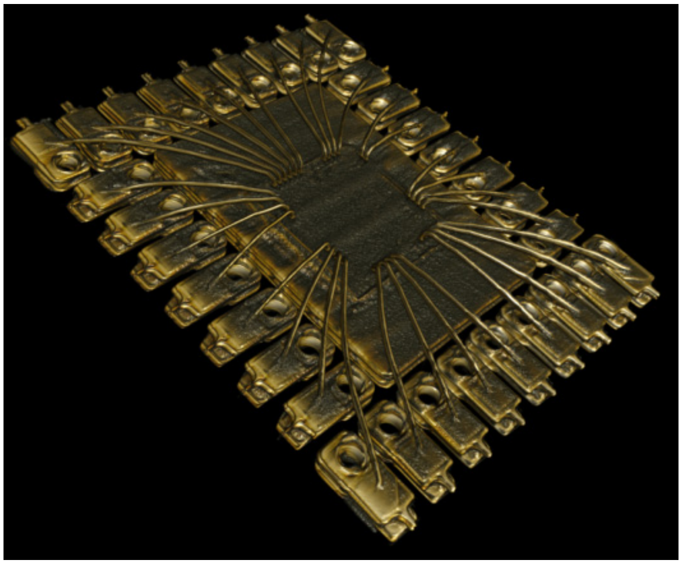


Figure 4– 3D µCT reconstruction of package

Figure 5– Close-up µCT of copper wirebond

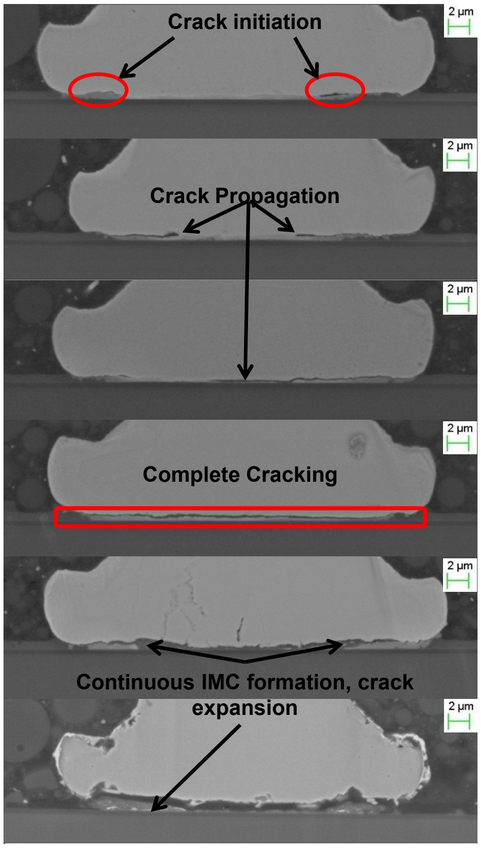


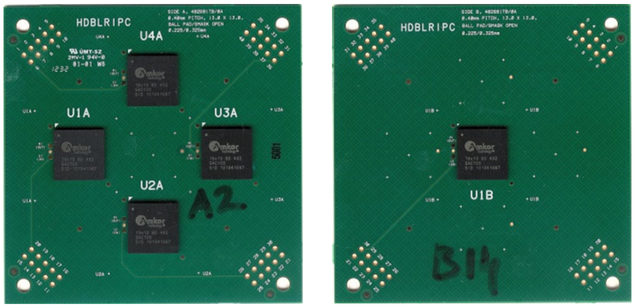
Figure 6 – Crack initiation and propagation

Formation of excessive Cu-Al intermetallics may increase electrical resistance and reduce the mechanical bonding strength. Current state-of-art for studying the Cu-Al system focuses on accumulation of statistically significant number of failures under accelerated testing. Damage in wire bonds has been studied using x-ray Micro-CT.

Microstructure evolution was studied under isothermal aging conditions of 150°C, 175°C, and 200°C till failure. Activation energy was calculated using growth rate of intermetallic at different temperatures. Effect of temperature and humidity on Cu-Al wirebond system was studied using Parr Bomb technique at different elevated temperature and humidity conditions (110°C/100%RH, 120°C/100%RH, 130°C/100%RH) and failure mechanism was developed. The present methodology uses evolution of the IMC thickness, composition in conjunction with the Levenberg-Marquardt algorithm to identify accrued damage in wire bond subjected to thermal aging. The proposed method can be used for quick assessment of Cu-Al parts to ensure manufactured part consistency through sampling.

CAVE3 Analyzes Candidate JESD22-B111 Board Designs for JEDEC Working-Group

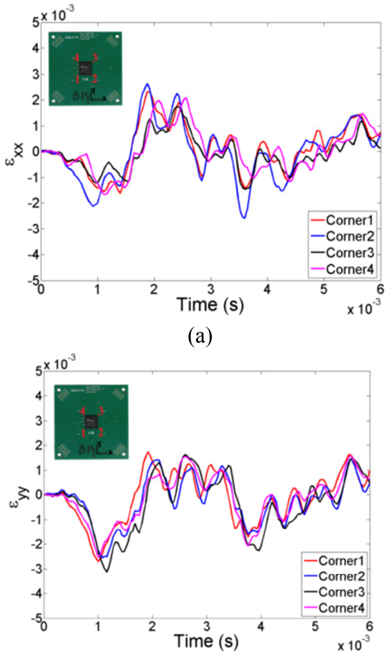
CAVE3 analyzed candidate board designs using Transient Dynamics Models and 3D-DIC Analysis in conjunction with high speed cameras. The existing configuration of the JESD22-B111 test board does not impose identical strains during drop test on all the 15-components on the test board, requiring a large numbers of boards to develop meaningful life distributions. Two new candidate designs intended to serve as replacements for the JEDEC JESD22-B111 test board have been analyzed. Configuration-A includes four components located symmetrically on a square 3-inch x 3-inch printed circuit board. Configuration-B includes one-component located symmetrically on a square 3-inch x 3-inch printed circuit board. In this paper, explicit finite element models along with high speed imaging in conjunction with 3D DIC measurements have been used to capture transient strain histories at various board locations to quantify the symmetry of loading during a 1500g 0.5 ms shock pulse and 2900g, 0.3 ms shock pulse.



(a) Test Board-A (b) Test-Board-B

Figure 7: (a) Test Board A with four BGA packages (b) Test Board B with single BGA package

The symmetry of the transient mode shapes and interconnect strains has also been quantified. For the one-component test board-B, model predictions experimental measurements of strain and deformation indicate that the strain field is symmetric at the corners of the component. For the four-component test board the model predictions and experimental data yielded mixed results. Model predictions indicate that the four-component test board-A has symmetric strain field and symmetric displacement field. However modal analysis indicates that not all the mode shapes would apply identical board deformation to the four components on the test board. Further, the intended symmetry of strain and displacement for the four component test board is realized in a limited manner because of manufacturing variability. Experimental data from high speed 3D-DIC measurements indicates that the strain traces the four-component inner corners have limited similarity but are not identical. Furthermore, strain traces the four-component outer corners have limited similarity also and are not identical.



(a)

(b)

Figure 8: (a) x-strain and (b) y-Strain in the PCB at location of the corner interconnects of one-component test board-B under 1500g shock-impact

Effects of Aging on the Anand Viscoplastic Constitutive Model for SAC305 Solder

Lead free solder materials are widely used in electronic packaging industry due to environmental concerns. However, experimental testing and microstructural characterization have revealed that Pb-free solders exhibit evolving properties that change significantly with environmental exposures such as isothermal aging and thermal cycling. These changes are especially large in harsh environments, where the effects of aging on solder joint behavior must be accounted for and included in constitutive models when predicting reliability. In this work, we have adapted the Anand viscoplastic stress-strain relations for Pb-free solders to include material parameters that evolve with the thermal history of the solder material. In particular, aging effects have been examined by performing uniaxial tensile tests on SAC305 samples that were aged for various durations (0-12 months) at temperature of 100 C. For each set of aging conditions, several sets of constant strain rate and temperature tests were conducted on the aged solder samples. Testing conditions included strain rates of 0.001, 0.0001, and 0.00001 (1/sec), and temperatures of 25, 50, 75, 100, and 125 C. Using the measured uniaxial test data, the Anand parameters were calculated for each set of aging conditions, and the effects of aging on the nine Anand model parameters were determined. Mechanical tests have been performed using both water quenched (WQ) and reflowed (RF) SAC305 samples (two unique specimen microstructures). In the case of the water quenched samples, there is rapid microstructural transitioning during the brief time that occurs between placing molten solder into the glass tubes and immersing the tubes in water bath.

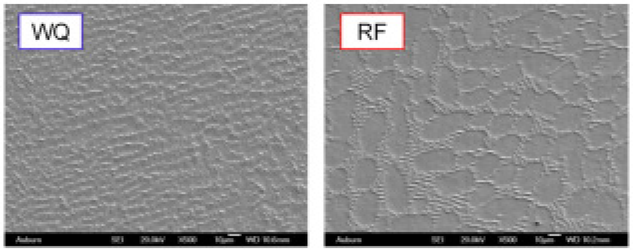


Figure 9: Comparison of SAC305 Microstructures [WQ and RF].

On the other hand, the reflowed samples are first cooled by water quenching, and then sent through a reflow oven to re-melt the solder in the tubes and subject them to a desired temperature profile matching that used in PCB assembly. From the experimental results, the differences between the extracted Anand model parameters of water quenched and reflowed samples were high for samples with no prior aging. As expected, the water quenched samples had much higher mechanical properties (stiffness and strength) than reflowed samples prior to aging. For both the water quenched and reflowed specimens, significant degradation of the mechanical properties was observed with aging. The variations of the Anand model parameters with aging time have been characterized and empirical relationships were established to model the observed changes. After long aging times, the water quenched and reflowed SAC305 materials were found to exhibit similar mechanical properties, and thus their Anand parameters converged and became nearly identical.

Effects of Moisture Exposure on the Mechanical Behavior of Polycarbonate Materials Used in Electronic Packaging

The mechanical properties of polymer materials are often a key concern of the microelectronic packaging industry. The theoretical analysis of stress, strain, and deformation induced in electronic assemblies due to environmental exposures such as moisture adsorption, isothermal aging, and thermal cycling require the complete characterization of mechanical properties and constitutive behavior of the constituent materials. In this work, an experimental investigation has been performed on the effects of moisture adsorption on the stress-strain behavior of polycarbonate materials used in electronic packaging. Uniaxial test specimens were exposed in a controlled temperature and humidity chamber to combined hygrothermal exposures at 60 C and 90% RH, 60 C and 50% RH, and 40 C and 50% RH for various durations. After moisture preconditioning, a microscale tension-torsion testing machine was used to evaluate the complete stress-strain behavior of the material at several temperatures (T = 20 C, 40 C, and 60 C). It was found that moisture exposure strongly affected the mechanical properties of the tested polycarbonate, especially ultimate strain limit. Reversibility tests were also conducted to evaluate whether the degradations in the mechanical properties were recoverable. Upon fully redrying, the material was found to recover most of its original mechanical properties. In addition, optical microscopy was utilized to examine the fracture surfaces of the failed specimens, and observe the influence of moisture exposure.

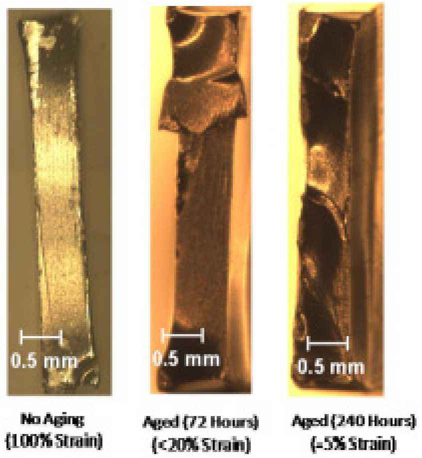


Figure 10: Fracture Surfaces of Samples with and without Moisture Absorption.

Characterization of Moisture and Thermally Induced Die Stresses in Flip Chip on Laminate Assemblies

Stress sensing test chips are a powerful tool for measuring in-situ stresses in electronic packages. In this study, we have applied (111) silicon test chips to perform a variety of measurements of moisture and thermally induced die stresses in flip chip on laminate assemblies. The developed chips incorporated optimized eight-element sensor rosettes that were capable of measuring the complete state of stress at the die surface (including the interfacial shear stresses). For the measurements completed in this work, the test chips were 10 x 10 mm in size, and contained 200 µm pitch perimeter solder bumps. Each chip contained 19 eight-element sensor rosettes, two diodes for temperature measurement, and a 10-bit fuse style chip ID. The fabricated test chips were initially utilized to measure the die stresses after solder reflow, after underfill dispense and cure, and as a function of temperature after cure. In later testing, samples were remeasured after long term storage (10 years) at room temperature and ambient humidity. The samples were then exposed to a harsh high temperature and high humidity environment (85 C, 85% RH) for various time durations, and allowed to adsorb moisture. The die stresses at several locations were characterized as a function of time during the hygrothermal exposure. The weight of each sample was also measured during the 85/85 exposure to gauge the moisture uptake, and reversibility testing was conducted. After long term storage, the experimental measurements showed that the normal stresses in the flip chip die relaxed significantly, while the shear stresses exhibited only small variations.

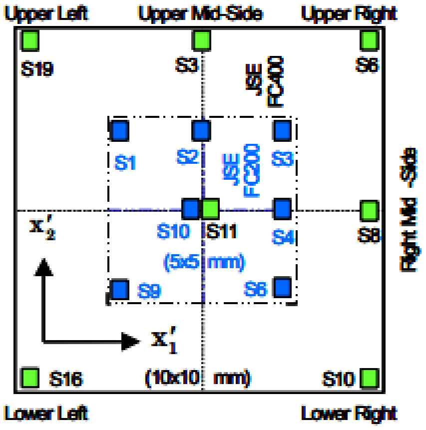


Figure 11: Critical Sensor Location.

In addition, the 85/85 hygrothermal exposure had strong effects, generating tensile die normal stress changes of up to 30 MPa in the flip chip assemblies. Thus, the initial compressive die normal stresses due to flip chip assembly were found to relax significantly during the moisture exposure. Reversibility tests were also conducted to see whether the effects of moisture uptake were permanent. Upon fully redrying, it was observed that the moisture-induced stress changes were fully recovered. A strong correlation was observed between the variation of sample weight (increase in moisture content) and the variation of the die normal stresses.

Vibrational Performance on Different Doped Low Creep Lead Free Solder Ball Grid Array Packages

Relatively little is known about the performance of the doped Ball Grid Array (BGA) packages used in semiconductor industries, even though newer products are widely being introduced to the market. This work experimentally investigates the doping effects of the BGA packages with SAC 305 alloys, caused by the vibration loading. This experiment focuses on the vibration fatigue life of 15 mm CABGA packages with 208 perimeter solder balls on a 0.8 mm pitch. The test boards were built to withstand JEDEC JESD22-B103B standards of high stress test in vibrational shaker table to assess the solder joint performance. The test boards are built with three different reflow profiles and two different stencil thicknesses 8 mil (6 mil with overprint) and 4 mil to study the differences in doping effect of the new doped alloys. The WLCSP assembly was subjected to accelerated life test of severe random vibration per board. The reliability of the component is determined by the ability of the components to withstand vibration as a result of motion produced by field operations. The deleterious effect of the mechanical loading of BGA's on the characteristic fatigue lifetime is reported. The results show that the material characteristics have a direct impact on the total time to failure.

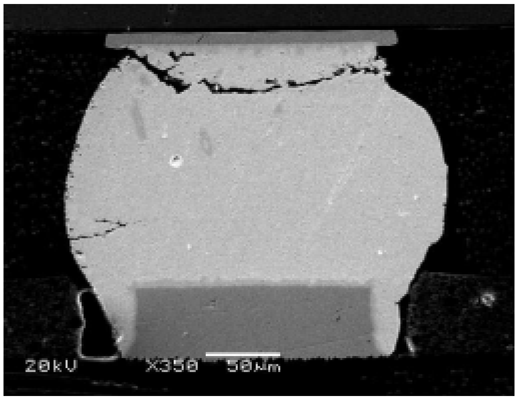


Figure 12: Microstructure Analysis Solder SAC305.

The results show that the Time-To- Failure (TTF) of the solder joint decreases with doping. The effectiveness of these characteristics was demonstrated with promising results through vibration testing of different lead free low creep alloys. This paper concludes with discussion of the deterioration intensity aging has on SAC alloys and the change in reliability due to doping.

Exploration of Aging Induced Evolution of Solder Joints Using Nanoindentation and Microdiffraction

Due to aging phenomena, the microstructure, mechanical response, and failure behavior of lead free solder joints in electronic assemblies are constantly evolving when exposed to isothermal and/or thermal cycling environments. In our ongoing studies, we are exploring aging phenomena by nano- mechanical testing of SAC lead free solder joints extracted from PBGA assemblies. Using nanoindentation techniques, the stress-strain and creep behavior of the SAC solder materials are being explored at the joint scale for various aging conditions. Mechanical properties characterized as a function of aging include the elastic modulus, hardness, and yield stress. Using a constant force at max indentation, the creep response of the aged and non-aged solder joint materials is also being measured as a function of the applied stress level. With these approaches, aging effects in actual solder joints are being quantified and correlated to the magnitudes of those observed in testing of miniature bulk specimens. In our initial work (ECTC 2013), we explored aging effects in single grain SAC305 solder joints. In the current investigation, we have extended our previous work on nanoindentation of joints to examine a full test matrix of SAC solder alloys. The effects of silver content on SAC solder aging has been evaluated by testing joints from SACN05 (SAC105, SAC205, SAC305, and SAC405) test boards assembled with the same reflow profile. In all cases, the tested joints were extracted from 14 x 14 mm PBGA assemblies (0.8 mm ball pitch, 0.46 mm ball diameter) that are part of the iNEMI Characterization of Pb-Free Alloy Alternatives Project (16 different solder joint alloys available). After extraction, the joints were subjected to various aging conditions (0 to 12 months of aging at T = 125 C), and then tested via nanoindentation techniques to evaluate the stress-strain and creep behavior of the four aged SAC solder alloy materials at the joint scale. The observed aging effects in the SACN05 solder joints have been quantified and correlated with the magnitudes observed in tensile testing of miniature bulk specimens performed in prior studies. The results show that the aging induced degradations of the mechanical properties (modulus, hardness) in the SAC joints were of similar order (30-40%) as those seen previously in the testing of larger "bulk" uniaxial solder specimens. The creep rates of the various tested SACN05 joints were found to increase by 8-50X due to aging.

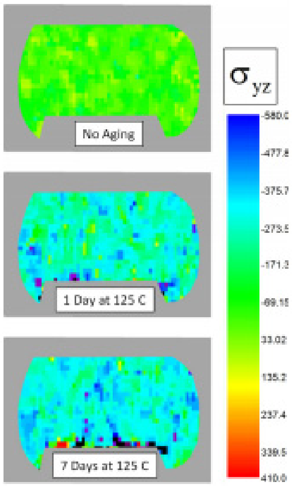


Figure 13: Measured Deviatoric Stress Distribution from Microdiffraction (SAC305).

These degradations, while significant, were much less than those observed in larger bulk solder uniaxial tensile specimens with several hundred grains, where the increases ranged from 200X to 10000X for the various SACN05 alloys. Additional testing has been performed on very small tensile specimens with approximately 10 grains, and the aging-induced creep rate degradations found in these specimens were on the same order of magnitude as those observed in the single grain joints. Thus, the lack of the grain boundary sliding creep mechanism in the single grain joints is an important factor in avoiding the extremely large creep rate degradations (up to 10,000X) occurring in larger bulk SAC samples. All of the aging effects observed in the SACN05 joints were found to be exacerbated as the silver content in the alloy was reduced. In addition, the test results for all of the alloys show that the elastic, plastic, and creep properties of the solder joints and their sensitivities to aging are highly dependent on the crystal orientation. The observed mechanical behavior changes in joints are due to evolution in the microstructure and residual strains/stresses in the solder material, and measurements of these evolutions are critical to developing a fundamental understanding of solder joint aging phenomena. As another part of this work, we have performed an initial study of these effects in the same SAC305 solder joints that were tested using nanoindentation. The enhanced x-ray microdiffraction technique at the Advanced Light Source (Synchrotron) at the Lawrence Berkeley National Laboratory was employed to characterize several joints after various aging exposures (0, 1, and 7 days of aging at T = 125 C). For each joint, microdiffraction was used to examine grain growth, grain rotation, sub-grain formation, and residual strain and stress evolution as a function of the aging exposure. The entire joints were scanned using a 10 micron step size, and the results were correlated with changes in the mechanical response of the joint specimens measured by nanoindentation.

Reliability of Solid-State Lighting Electrical Drivers Subjected to WHTOL Accelerated Aging

An investigation of a solid-state lighting (SSL) luminaire with the focus on the electronic driver which has been exposed to a standard wet hot temperature operating life (WHTOL) of 85% RH and 85°C in order to assess reliability of prolonged exposer to a harsh environment has been conducted. SSL luminaires are beginning introduced as headlamps in some of today's luxury automobiles and may also be fulfilling a variety of important outdoor applications such as overhead street lamps, traffic signals and landscape lighting. SSL luminaires in these environments are almost certain to encounter excessive moisture from humidity and high temperatures for a persistent period of time. The lack of accelerated test methods for LEDs to assess long-term reliability prior to introduction into the marketplace, a need for SSL physics based PHM modeling indicators for assessment and prediction of LED life, as well as the U.S. Department of Energy's R&D roadmap to replace todays lighting with SSL luminaires makes it important to increase the understanding of the reliability of SSL devices, specifically, in harsh environment applications. In this work, a set of SSL electrical drivers were investigated to determine failure mechanisms that occur during prolonged harsh environment applications. Each driver consists of four aluminum electrolytic capacitors (AECs) of three different types and was considered the weakest component inside the SSL electrical driver. The reliability of the electrical driver was assessed by monitoring the change in capacitance and the change in equivalent series resistance for each AEC, as well as monitoring the luminous flux of the SSL luminaire or the output of the electrical driver. The luminous flux of a pristine SSL electrical driver was also monitored in order to detect minute changes in the electrical drivers output and to aid in the investigation of the SSL luminaires reliability. The failure mechanisms of the electrical drivers have been determined and are presented in this paper.

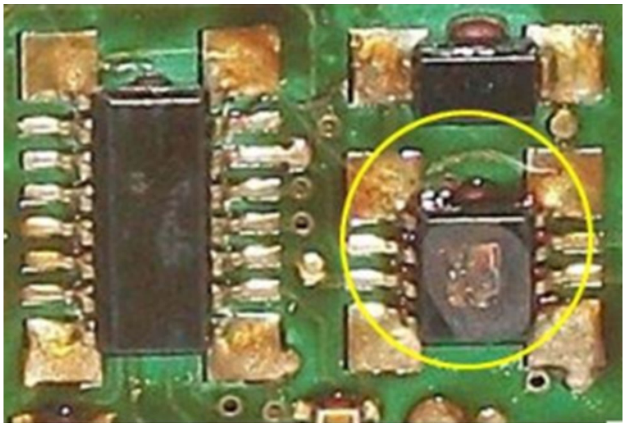


Figure 11: Failure Mechanism of WHTOL Driver One.

Auburn University Students Receive the Best-Poster Paper Awards at the ITHERM 2014.

The following AU papers received Best-Poster Paper Awards in at the IEEE ITHERM 2014 Conference held in Orlando, Florida. Papers 1-2 received the awards in the Mechanics Track. Paper-3 received the award in the Thermal Track :

Lall, P., Deshpande, S., Nguyen, L., Murtuza, M., Damage Mechanisms in Copper-Aluminum Wirebonds under High Temperature Operations, Proceedings of the 14th ITHERM, May 27-30, 2014.

Mustafa, M., Roberts, J., Suhling, J., Lall, P., Effects of Aging on Shear Cyclic Stress Strain and Fatigue Behaviors of Lead Free Solder Joints, Proceedings of the 14th ITHERM, May 27-30, 2014.

Gess, J., Bhavnani, S., Ramakrishnan, B., Johnson, W., Harris, D., Knight, R., Hamilton, M., Ellis, C., Impact of Surface Enhancements upon Boiling Heat Transfer in a Liquid Immersion Cooled High Performance Small Form Factor Server Model, Proceedings of the 14th ITHERM, May 27-30, 2014.

The poster awards were recognized at the Awards Luncheon at the IEEE ITHERM 2014 Conference.

Pictured Left-to-Right Award Winning Papers recognized by Mehdi Asheghi (Stanford U) Far-Left; Authors: Jeff Suhling (AU), Muhannad Mustafa (AU), Pradeep Lall (AU), Shantanu Deshpande (AU), Joshua Gess (AU), Sushil Bhavnani (AU)

Lall Elected Fellow of the Alabama Academy of Sciences

Pradeep Lall, Thomas Walter professor in Auburn University's Department of Mechanical Engineering and director of Auburn's National Science Foundation Center for Advanced Vehicle and Extreme Environment Electronics, has been selected as a fellow of the Alabama Academy of Science, the academy's second highest honor. The academy recognizes several individuals annually for their contributions to the field of science in Alabama and for their service to the academy. Lall accepted the award at the 91st annual meeting, held this spring at Auburn University. Lall has served as a member of the Auburn faculty since 2002. A well-recognized researcher in the field of electronics reliability and prognostics, Lall is the recipient of the Surface Mount Technology Association's Member of Technical Distinction Award, as well as the SEC's Auburn University Faculty Achievement Award and the College of Engineering's Senior Faculty Research Award. He has received three Motorola Outstanding Innovation Awards, five Motorola Engineering Awards and 23 best paper awards at national and international conferences. "I am honored and humbled to be chosen as one of the 2014 fellows of the Alabama Academy of Science," said Lall. "The academy has played a key role in encouraging the development and study of sciences within the state of Alabama. The topic of extreme environment electronics is of high relevance to aerospace, defense and automotive companies in the state. I look forward to continue making a lasting impact on the design and manufacture of electronic products in the state of Alabama through my research in electronics packaging, reliability, and prognostics."

Lall Honored with IEEE-CPMT Exceptional Technical Achievement Award

(*Contd from Page-1*) Prof. Lall's seminal work in the use of high speed imaging with speckle methods for measurement of interconnect and board assembly strains under shock and vibration has enabled the development of solutions for electronics survivability in high-g environments. His research on the development of multiscale predictive methods for electronics reliability under shock, drop, and vibration has enabled product level evaluation of stresses on fine-pitch interconnects in devices. The award is conferred on individuals whose technical contributions are considered exceptional not achieved by most members. Contributions considered include a significant invention, introduction of new and important technology or a significant work that advances the state of art. Award winners receive a monetary award of $2500 along with a certificate of achievement. The award was conferred at the 64th IEEE Electronics Components and Technology Conference (ECTC) held in Orlando, Florida. ECTC is the premier international conference in the subject area of packaging, components and microelectronic systems science, and technology which was attended by over 1200 people from over 25 countries.

CAVE3 Students Travel to ITHERM 2014 Conference in Orlando to present Technical Papers

Several students attended the IEEE ITHERM 2014 to present papers, as well as participate in the poster competition. In all CAVE3 researchers presented 16 papers at IEEE ITHERM 2014. Students attending the conference included: Shantanu Deshpande, Peter Sakalaukus, Junchao Wei, Di Zhang, Vikas Yadav, Amrit Abrol, Mohammad Motalab, Muhannad Mustafa, Munchi Basit, Mohammad Hasnine, Nusrat Chhanda, Safina Hussain, Quang Nguyen, and Jordan Roberts. Faculty attending included: Professors Pradeep Lall and Jeff Suhling.

Selected Recent Publications

1. Basit, M., Motalab, M., Suhling, J., Lall, P. "The Effects of Aging on the Anand Viscoplastic Constitutive Model for SAC305 Solder." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
2. Motalab, M., Basit, M., Suhling, J., Bozack, M., Lall, P. "Creep Test Method for Determination of Anand Parameters for Lead Free Solders and their Variation with Aging." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
3. Mustafa, M., Roberts, J., Suhling, J., Lall, P. "Effects of Aging on Shear Cyclic Stress Strain and Fatigue Behaviors of Lead Free Solder Joints." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
4. Hasnine, M., Suhling, J., Prorok, B., Bozack, M., Lall, P. "Nanomechanical Characterization of SAC305 Solder Joints – Effects of Aging." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
5. Lall, P., Yadav, V., Zhang, D., Suhling, J., Shantaram, S. "High Strain Rate Mechanical Properties of SAC105 Lead-free Alloy at High Operating Temperatures." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
6. Chhanda, N., Suhling, J., Lall, P. "Effects of Moisture Exposure on the Mechanical Behavior of Flip Chip Underfills in Microelectronic Packaging." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
7. Chhanda, N., Suhling, J. "Effects of Moisture Exposure on the Mechanical Behavior of Polycarbonate Materials Used in Electronic Packaging." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
8. Basit, M., Motalab, M., Roberts, J., Suhling, J., Lall, P. "The Effects of Silver Content and Solidification Profile on the Anand Constitutive Model for SAC Lead Free Solder." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
9. Nguyen, Q., Roberts, J., Suhling, J., Jaeger, R. "Characterization of Moisture and Thermally Induced Die Stresses in Flip Chip on Laminate Assemblies." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
10. Thirugnanasambandam, S., Sanders, T., Raj, A., Stone, D., Evans, J., Flowers, G., Suhling, J. "The Study of Vibrational Performance on Different Doped Low Creep Lead Free Solder Paste and Solder Ball Grid Array Packages." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
11. Lall, P., Sakalaukus, P., Davis, L. "Reliability of Solid-State Lighting Electrical Drivers Subjected to WHTOL Accelerated Aging." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
12. Lall, P., Deshpande, S., Nguyen, L., Murtuza, M. "Damage Mechanisms in Copper-Aluminum Wirebonds under High Temperature Operations." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
13. Lall, P., Sakalaukus, P., Wei, J., Davis, L. "SSL and LED Life Prediction and Assessment of CCT Shift." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
14. Hussain, S., Jaeger, R., Suhling, J., Wilamowski, B., Hamilton, M., Gnanachchelvi, P. "Understanding the Impact of Temperature Variations on Measurement of Stress Dependent Parameters of Bipolar Junction Transistors." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
15. Lall, P., Zhang, D., Yadav, V., Suhling, J., Shantaram, S. "Material Behavior of SAC305 under High Strain Rate at High Temperature." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
16. Lall, P., Abrol, A., Simpson, L., Glover, J. "Reliability of MEMs Devices under Multiple Environments." Proceedings of the 14th InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm 2014). May 27-30, 2014.
17. Lall, P., Dornala, K., Zhang, D. "Transient Dynamics Model and 3D-DIC Analysis of New-Candidate for JEDEC JESD22-B111 Test Board." 64th Electronic Components & Technology Conference (ECTC 2014). May 27-30, 2014.
18. Lall, P., Deshpande, S., Luo, Y., Bozack, M., Nguyen, L., Murtuza, M. "Degradation Mechanisms in Electronic Mold Compounds Subjected to High Temperature in Neighborhood of 200°C." 64th Electronic Components & Technology Conference (ECTC 2014). May 27-30, 2014.
19. Hasnine, M., Suhling, J., Prorok, B., Bozack, M., Lall, P. "Exploration of Aging Induced Evolution of Solder Joints Using Nanoindentation and Microdiffraction." 64th Electronic Components & Technology Conference (ECTC 2014). May 27 -30, 2014.
20. Mustafa, M., Roberts, J., Suhling, J., Lall, P. "The Effects of Aging on the Fatigue Life of Lead Free Solders." 64th Electronic Components & Technology Conference (ECTC 2014). May 27-30, 2014.
21. Lall, P., Mirza, K., Suhling, J. "Damage Pre-Cursor Based Life Prediction of the Effect of Mean Temperature of Thermal Cycle on the SnAgCu Solder Joint Reliability." 64th Electronic Components & Technology Conference (ECTC 2014). May 27

-30, 2014.

22. Lall, P., Deshpande, S. “Non-Destructive Crack and Defect Detection in SAC Solder Interconnects Using Cross-Sectioning and X-Ray Micro-CT.” 64th Electronic Components & Technology Conference (ECTC 2014). May 27-30, 2014.
23. Lall, P., Deshpande, S. Nguyen, L., Murtuza, M. “Prognostication of Copper-Aluminum Wirebonds Reliability under High Temperature Storage and Temperature-Humidity.” 64th Electronic Components & Technology Conference (ECTC 2014). May 27-30, 2014.
24. Lall, P., Wei, J., Sakalaukus, P. “Life Prediction and Classification of Failure Modes in Solid-State Luminaires Using Bayesian Probabilistic Models.” 64th Electronic Components & Technology Conference (ECTC 2014). May 27-30, 2014.21.

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