AUBURN UNIVERSITY
SAMUEL GINN
COLLEGE OF ENGINEERING

Spring 2015

cave³ News

NSF-CAVE3 Electronics Research Center
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INSIDE

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.

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Message from Director

Manufacturing plays a key role in spurring innovation and economic development. The recent call for proposals for the formation of a National Network for Manufacturing Innovation focuses on the topic of Flexible Hybrid Electronics. Auburn University is leading a consortium of universities and companies in response to the FOA for an IMI on the topic of Flexible Hybrid Electronics. The team in addition to AU consists of Purdue University, Rutgers University, Stanford University, University of Maryland, University of Texas at Arlington, and Washington State University. Companies in the team consist of key players from categories of material suppliers, equipment makers and system integrators. Flexible electronics has been identified as one of the frontier goals by the National Academies of Engineering Reports on Leading Edge Engineering in 2013. In order to make flexible electronics possible, processes must meet the demands of soft, pliant and often easily damaged surfaces. Compatibility with delicate surface often requires low temperature processing. There are no large flexible electronics manufacturing firms in the US engaged in large scale commercial manufacturing of products that integrate flexible and printed electronics technologies. Thirty years ago when large corporate laboratories were prevalent, applied research and practical application of science used to be an area of strength in the United States. However, pricing pressures, commoditization of products, and the migration of manufacturing to the Far East has resulted in the downsizing and many cases elimination of the corporate research laboratories. There is a chasm between the laboratory research and the realization of commercialized products. The global flexible electronics industry is in its infancy as scaled up production for commercial applications exists in only a few niche areas including e-paper, RFID tags and organic light emitting diode screens. An IMI in the area of flexible electronics will fill in the void between lab research and commercial products. The semiconductor manufacturing is highly automated, utilizing complex processes developed by multiple vendors which cannot be readily integrated without coordination between players. The manufacturing challenges exist at multiple levels including raw materials, material handling, fabrication and assembly. Processing at low temperatures on conformal bendable, stretchable and foldable substrates is needed or device assembly integration. Adequate survivability in harsh applications will require development of flexible encapsulation approaches in addition to physical packaging and common interconnects and interfaces. Stretchable electronics will need device designs for mitigating the interconnect failures due to fracture and delamination under large deformation and strain. Innovative thermal management schemes are needed to ensure thermal and thermo-mechanical survivability in the presence of multi-material thin-film interfaces. In parallel with the development of manufacturing protocols, it is envisioned that the development of modeling tools and prediction methods is needed to assess the device design, layout, and fabrication parameters. Accelerated test methods and test conditions which have been developed for rigid electronics will need to be scaled to flexible hybrid electronics. The existence of the prior research expertise in the area of harsh environment electronics for automotive and military environments uniquely positions the AU led team to put together a successful IMI in the area of flexible hybrid electronics.

- Pradeep Lall, T. Walter Professor and Director

CAVE^3 Consortium Fall-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 September 9-10, 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

Contact Information:
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SPECIAL EVENTS

2015 IEEE International Conference on Prognostics and Health Management

June 22-25, 2015
University of Texas at Austin
Austin, TX

Professor Pradeep Lall is serving as the General Chair of the 5th Annual IEEE Reliability Society PHM conference will be held June 22-25 at University of Texas at Austin, 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.

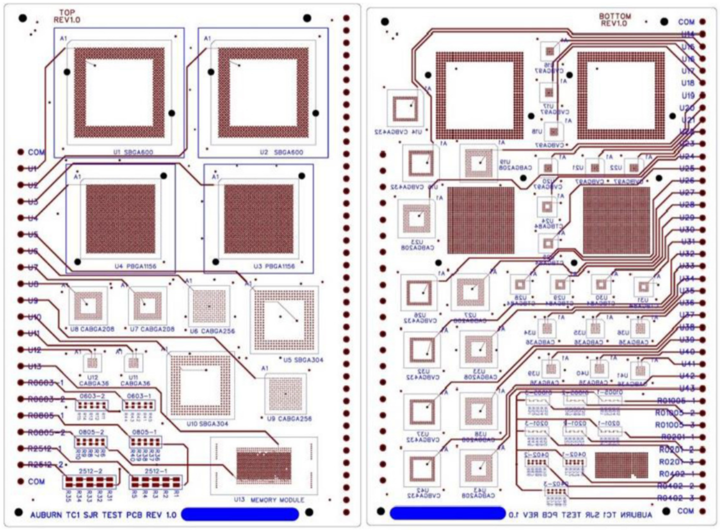
SMTA International 2015

Conference: Sep. 27—Oct. 1, 2015
Exhibition: Sep. 29—Sep. 30, 2015
Donald Stephens Convention Center
Rosemont, IL

CAVE3 is co-organizer for the Harsh Environments Workshop at the SMTAI Conference to be held at the Donald Stephens Convention Center in Rosemont, Illinois from Sept 27-Oct 1, 2015. The workshop will be jointly chaired by Prof(s) Pradeep Lall (AU), John Evans (AU), and Dr. Robert Kinyanjui (John Deere). Abstract submission is presently open till March 13, 2015. The workshop focuses on issues of relevance to the use of electronics in extreme environment applications. The papers will focus on environments including thermal, thermo-mechanical, vibration, mechanical shock, corrosion, and contamination. Design methods for the use of commercial off the shelf electronics in extreme environments will be presented in addition to modeling and design methods to ensure survivability over lifetimes much longer than expected in consumer applications. SMTAI has been recognized as a truly different type of industry event because of the high quality technical information and the networking opportunities that cannot be found anywhere else in the industry. Abstract Submission can be accessed at http://www.smta.org/smtai/call_for_papers.cfm

Leadfree Reliability for High Performance Computing

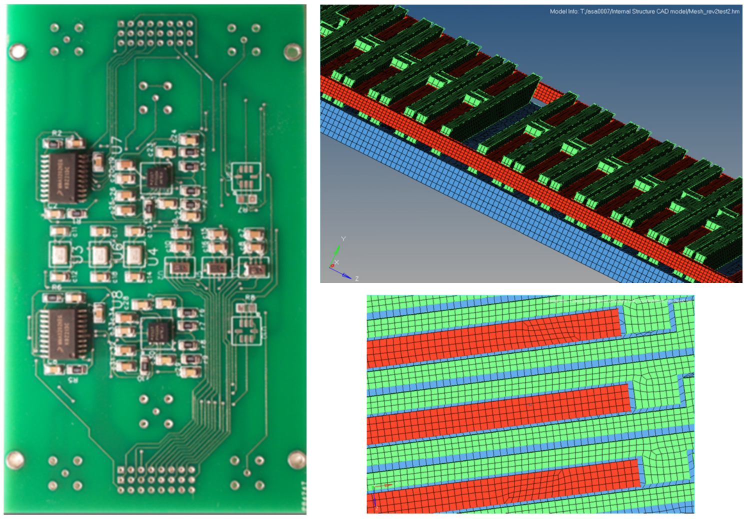
In this project, CAVE3 researchers are studying the reliability of a variety of different electronic components soldered on 200-mil thickness power computing printed circuit boards. Two substrate materials – FR4-06 and Megtron6 – are considered. The primary solder for package attachment in this experiment is standard SAC305. Additionally, several solders designed for high-temperature reliability have been tested including SnPb and Innolot. The principal test components included in the study are 5 mm, 6mm, 13mm, 15mm, 17mm, 31mm, 35mm and 45 mm ball grid array (BGA) packages with solder ball pitch varying from 0.4 mm to 1.27 mm. Several surface mount resistors (SMRs) are also included in order to understand the effect of solder paste composition on conventional packages. In addition, the effect of heat-sinks versus no heat-sinks is also being studied for the 35 mm and 45 mm SBGA packages. Single-sided assemblies were built separately for the Top-side and Bottom-side of the boards. The assemblies were subjected thermal cycles of -40°C to +125°C on a 120 minute thermal profile. The test was subject to JEDEC JESD22-A104-B standard high and low temperature test in a single-zone environmental chamber to assess the solder joint performance. Innolot solder based CABGA 208, CABGA256, PBGA1156 soldered to FR406 has been found to be more reliable than eutectic tin-lead and SAC305.



Solder Joint Reliability Test Board

Reliability of MEMS Devices in Extreme Environments

Micro-electro-mechanical systems (MEMS) devices are used in a variety of applications for sensing acceleration, translation, rotation, pressure and sound in addition to actuation and signal generation. The MEMS devices have been applied to varied fields including healthcare and automotive applications. Data on reliability degradation of MEMS devices in harsh environment applications including combined environments of high temperature exposure, and high -g shock loading is scarce. In this project, a test vehicle with a MEMS Accelerometers has been studied under high-temperature exposure followed by high-g mechanical shock. Test boards have been designed to assemble all the sensor types. The boards have been subjected to mechanical shocks using the method 2002.5, condition G, under the standard MIL-STD-883H test. Shock pulse amplitudes have been ramped from 500 to 30,000g with pulse duration between 0.1 to 1 millisecond. Full field effect on the components has been extracted using high speed cameras operating at 100,000 fps in conjunction with digital image correlation. The degradation of the MEMS response has been studied using statistical pattern recognition. The failure mechanisms have been characterized. The deterioration of the components has been extracted using non-destructive evaluation with micro-CT scans and X-ray. Further, the degradation of the MEMS response has been studied using statistical pattern recognition. The failure mechanisms have been characterized.



(a) Picture of the test board with MEMS sensors soldered to the board assembly (b) Test board in vertical drop orientation for survivability testing under mechanical shock.

L70 Life Prediction for Solid State Lighting Using Kalman Filter and Extended Kalman Filter Based Models

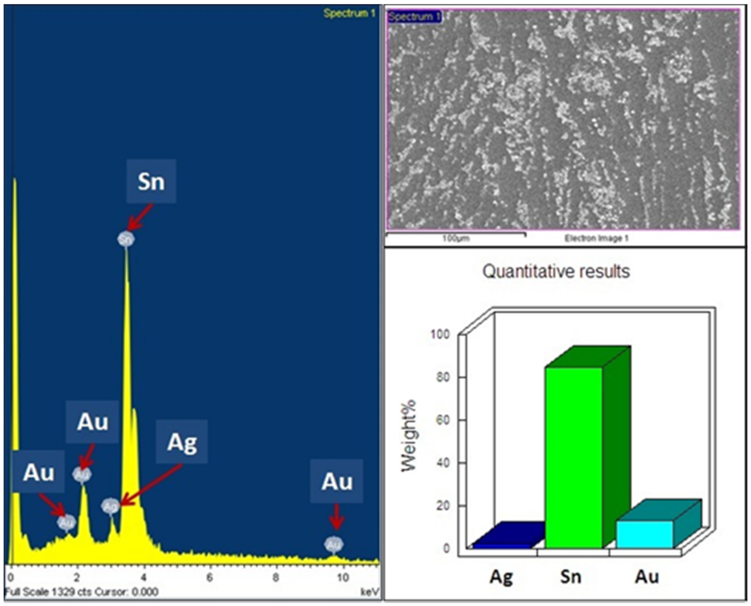
Solid-state lighting (SSL) luminaires containing light emitting diodes (LEDs) have the potential of seeing excessive temperatures when being transported across country or being stored in non-climate controlled warehouses. They are also being used in outdoor applications in desert environments that see little or no humidity but will experience extremely high temperatures during the day. This makes it important to increase our understanding of what effects high temperature exposure for a prolonged period of time will have on the usability and survivability of these devices. Traditional light sources “burn out” at end-of-life. For an incandescent bulb, the lamp life is defined by B50 life. However, the LEDs have no filament to “burn”. The LEDs continually degrade and the light output decreases eventually below useful levels causing failure. Presently, the TM-21 test standard is used to predict the L70 life of LEDs from LM-80 test data. Several failure mechanisms may be active in a LED at a single time causing lumen depreciation. The underlying TM-21 Model may not capture the failure physics in presence of multiple failure mechanisms. Correlation of lumen maintenance with underlying physics of degradation at system-level is needed. A Kalman Filter (KF) and Extended Kalman Filters (EKF) have been used to develop a 70-percent Lumen Maintenance Life Prediction

Model for LEDs used in SSL luminaires. Ten-thousand hour LM-80 test data for various LEDs have been used for model development. System state at each future time has been computed based on the state space at preceding time step, system dynamics matrix, control vector, control matrix, measurement matrix, measured vector, process noise and measurement noise. The future state of the lumen depreciation has been estimated based on a second order Kalman Filter model and a Bayesian Framework. The measured state variable has been related to the underlying damage using physics-based models. Life prediction of L70 life for the LEDs used in SSL luminaires from KF and EKF based models have been compared with the TM-21 model predictions and experimental data.

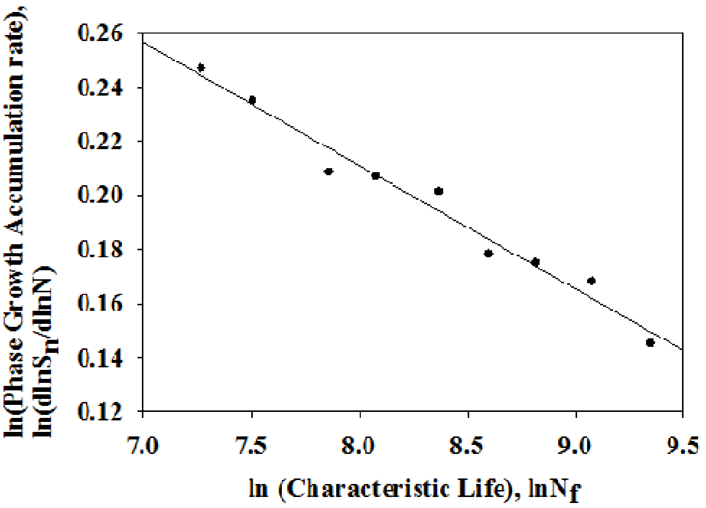
Luxeon LXM3-PW LED.

Mapping Leadfree Electronics Reliability Between Different Use Conditions

Electronics in functional products may be often subjected to a variety of thermal excursions during storage, operation and handling. One such variation occurs when electronic components may be subjected to differing mean temperatures while the amplitude of the cyclic thermal excursion which is governed by the power-on and power-off cycling may be constant. Prior studies have shown that low silver lead-free SnAgCu alloys exhibit pronounced deterioration in mechanical properties even after short exposure to high temperatures. The failure thresholds and the damage accumulation behavior is thus evolving with the time of exposure to high temperatures. Current life prediction models for second level interconnects do not provide a method for quick-turn assessment of the effect of mean temperature on cyclic life. In this project, a method has been developed for assessment of the effect of mean cyclic temperature on the thermal fatigue reliability based on physics based leading damage indicators including phase-growth rate and the intermetallic thickness. Since the quantification of the thermal profile in the field applications may be often very difficult, the proposed method does not require the acquisition of the thermal profile history. Three environments of -50°C to +50°C, 0°C to 100°C, 50°C to 150°C with identical thermal excursion and different mean temperatures have been studied. Test assemblies with three different packages including CABGA 144, PBGA 324, and PBGA 676 have been used for the study. Damage-proxy based damage-equivalency relationships have been derived for the three thermal cycles. Weibull distributions have been developed for the three test assemblies to evaluate the effect of the mean cyclic temperature on the thermal fatigue life. Data indicates that the thermal fatigue lie drops with the increase in mean temperature of the thermal cycle even if the thermal excursion magnitude is kept constant. Damage equivalency model predictions of the effect of mean temperature of the thermal cycle have been validated versus weibull life distributions. The damage proxy based damage equivalency methodology shows good correlation with experimental data.



EDS Analysis to Identify Phase Growth in the Solder Joints as a Pre-Cursor to Accumulation of Damage and Thermo-mechanical Fatigue.

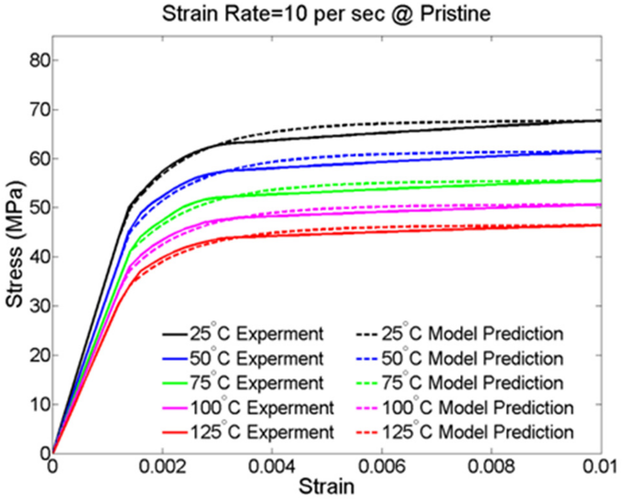


Mapping of the Damage Pre-cursor with the time to 63.2-percent failure of the population for three different part architectures with SAC305 solder joints subjected to 3-different thermal cycles with same amplitude and different mean temperature.

Research Highlights

High Strain Rate Anand Viscoplasticity Constants Developed For SAC105 and SAC305 Leadfree Solder

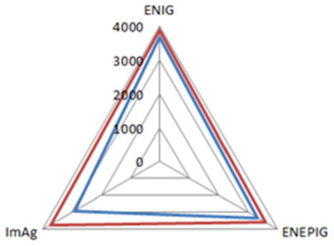
Leadfree solders have been used as interconnects in electronic packaging, due to its environmental friendly chemical property. However, those materials may experience high strain rates when subjected to shock and vibration. Consequently, failure will occur to electronics in those situations. Therefore, knowing the material properties of lead-free solders are extremely important, but research on mechanical behaviors of those solder alloys at high strain rates are scarce. Anand's viscoplastic constitutive model has been widely used to describe the inelastic deformation behavior of solders in electronic components under thermo-mechanical deformation. However, Anand's model constants for the transient dynamic strain rates are not available. In this project, the nine material parameters to fit the Anand viscoplastic model at high strain rates have been computed based on experimental measurements. In order to develop the constants for this model, uniaxial tensile tests at several strain rates and temperatures have been completed. A constant strain rate impact hammer which enables attaining strain rates around 1 to 100 per sec has been employed to implement tensile tests and a small thermal chamber is applied to control testing temperature. High speed cameras operating at 70,000 fps have been used to capture images of specimen and then digital image correlation method is used to calculate tensile strain. Uniaxial stress-strain curves have been plotted over a wide range of strain rates (10, 35, 50, 75 /sec) and temperatures (T = 25, 50, 75, 100, 125°C). Anand viscoplasticity constants have been calculated by non-linear fitting procedures. In addition, the accuracy of the extracted Anand constants has been evaluated by comparing the model prediction and experimental data.



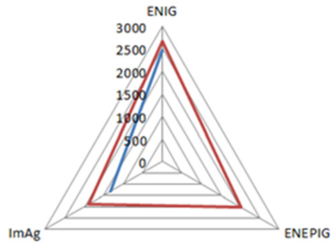
Correlation between the Experimental Measurements of Stress-Strain Behavior and Model Predictions of the Stress-Strain Behavior using Anand Viscoplasticity Constants for Strain-rate of 10sec^{-1}.

Effect of Prolonged Thermal Storage on Leadfree Electronics Reliability

In this study, the effects of prolonged thermal aging on the thermo-mechanical solder joint reliability has been studied for Sn-1.0Ag-0.5Cu (SAC105) and Sn-3.0Ag-0.5Cu (SAC305) ball grid array (BGA) solder joints on three board finishes (ImAg, ENIG, ENEPIG). Weibull analysis after 125°C thermal aging shows that the characteristic lifetimes for both SAC105 and SAC305 decrease in the following order for the board finishes included in the study: ENIG > ENEPIG > ImAg. Failure analysis shows continuous growth of Cu-Sn intermetallic compounds (IMC) on SAC/ImAg systems and Cu-Ni-Sn IMC on SAC/ENIG/ENEPIG systems at board side solder joints, which eventually cause fatigue failures. SAC305, with a higher relative fraction of Ag3Sn IMC within the solder, performs better than SAC105. SAC105 undergoes a considerable lifetime reduction during aging and illustrates the risk in using SAC105 solder balls in applications where thermal fatigue failure is a concern. In all cases, SAC305 solder alloy using ImAg, ENIG, or ENEPIG has a longer lifetime than SAC105, both with or without thermal aging. It is hypothesized that the presence of embedded Ag3Sn particles which form in the solder during aging causes the higher Ag content solder balls (SAC305) to perform better than SAC105.



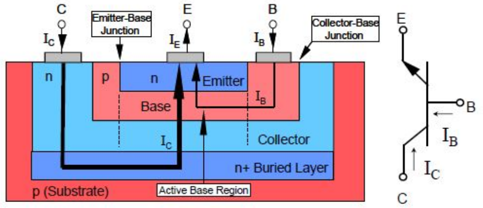
No aging



12M

The Influence of Uniaxial Normal Stress on the Performance of Vertical Bipolar Transistors

In this project the response of bipolar junction transistors (BJT) to the controlled application of mechanical stress has been expolored. Mechanical strains and stresses are developed during the fabrication, assembly and packaging of the integrated circuit (IC) chips. Due to these stresses and strains, it has been observed by many researchers that changes can occur in the electrical performance of both analog and digital devices. In this present work, the stress dependence of the electrical behavior of bipolar transistors has been investigated. Test structures have been utilized to characterize the stress sensitivity of vertical bipolar devices fabricated on (100) silicon wafers. In the experiments, uniaxial normal stresses were applied to silicon wafer strips using a four-point-bending fixture. An approximate theory has also been developed for stress-induced changes in the current gain of bipolar junction transistors. Both the theoretical and experimental results show similar trend for DC current gain vs. stress plots.



Announcements

Auburn University to Head a Team for the IMI on Flexible Hybrid Electronics

Auburn University is leading a team of universities and companies for proposal of an IMI on the topic of flexible hybrid electronics. The team in addition to AU consists of Purdue University, Rutgers University, Stanford University, University of Maryland, University of Texas at Arlington, and Washington State University. In addition to universities, the team includes several material suppliers, processing companies, and system integrators for electronics in the flexible hybrid electronics supply chain. The proposed IMI targets the creation of an ecosystem for flexible hybrid microelectronics. Companies with interest in joining the IMI should contact Professor Pradeep Lall at lall@auburn.edu for additional information.

CAVE3 Researchers present papers at the SMTAI and IMECE Conferences

CAVE3 researchers presented several papers at the SMTAI 2014 in Rosemont, Illinois and at the ASME International Congress and Exposition (IMECE) 2014 in Montreal, Canada. The following papers were presented at the conferences.

- ◊ Lall, P., Zhang, D., Yadav, V., Locker, D., Measurement of the High Strain Rate Mechanical Behavior of SAC305 Alloy at Product Operating Temperature and Derivation of Anand Viscoplasticity Constants, Proceedings of the SMTAI, Rosemont, IL, pp. 284-292, September 28-October 2, 2014.
- ◊ Lall, P., Mirza, K., Assessment of the Effect of Mean Temperature on Thermal Cycling Reliability of SAC Solder Joints Using Leading Indicators of Failure, Proceedings of the SMTAI, Rosemont, IL, pp. 373-387, September 28-October 2, 2014.
- ◊ Thirugnanasambandam, S., Sanders, T., Evans, J., Bozack, M., Johnson, W., Suhling, J., Component-Level Reliability for High Temperature Power Computing with SAC305 and Alternative High Reliability Solders, Proceedings of the SMTAI, Rosemont, Illinois, pp. 262-270, September 28-October 2, 2014
- ◊ Shen, C., Hai, Z., Zhao, C., Zhang, J., Evans, J., Bozack, M., The Effect of Isothermal Aging on the Reliability of Sn-Ag-Cu Solder Joints Using Various Surface Finishes, Proceedings of the SMTAI, Rosemont, Illinois, pp. 992-999, September 28-October 2, 2014
- ◊ Lall, P., Deshpande, S., Wei, J., X-ray Micro-CT for Non-Destructive Analysis of Cracks and Defects in Fine-Pitch Electronic Packages, Proceedings of the SMTAI, Rosemont, IL, pp. 757-764, September 28-October 2, 2014.
- ◊ Lall, P., Deshpande, S., Nguyen, L., High Temperature Storage and HAST Reliability of Copper-Aluminum Wirebond Interconnects, ASME International Congress and Exhibition (IMECE), Montreal, Canada, Paper Number IMECE2014-39524, Session 13-17-1, pp. 1-14, November 14-20, 2014.
- ◊ Lall, P., Zhang, D., Yadav, V., High Strain Rate Constitutive Behavior of SAC305 Solder During Operation at High Temperature, ASME International Congress and Exhibition (IMECE), Montreal, Canada, Paper Number IMECE2014-39518, Session 13-15-1, pp. 1-9, November 14-20, 2014.

Lall teaches a Professional Development Course at the SMTAI 2014

Prof. Lall taught a short course on the shock impact reliability of portable electronics at the SMTAI 2014 in Rosemont, Illinois on September 28, 2014. Portable electronics such as smartphones, tablets and laptops may be subjected to shock and vibration in transportation handling and normal usage. Fine-pitch electronic components are placed in ever closer vicinity of the product housing. The products may be dropped from ear-level, waist-level or desk-level depending on application. Electronic components may be subjected to several thousand-g's of acceleration often causing damage to interconnects and silicon devices mounted on the circuit-board in addition to LED displays. Presently, the JEDEC test standard JESD22-B111 is used to test component robustness. However, ensuring robustness of products in shock-impact is more involved comprising decisions regarding modeling of individual components, interfaces, board assemblies, housing materials and interactions. An analyst must make decisions regarding model complexity, constitutive behavior, initial conditions and multi-surface contact during the drop event. High-speed experimental techniques are needed to capture the event. The course introduced the students to Shock-survivability modeling and experimental techniques for electronic systems.

Lall serves as the Chair of the Congress Steering Committee Senate for ASME Congress 2014

Professor Lall served as the chair of the Steering Committee Senate for the ASME Congress 2014 which was held in Montreal, Canada. The ASME Congress is on the largest interdisciplinary meetings in the world. The 2014 Congress was attended by over 3000 attendees from more than 70-countries. Topics presented at the Congress included diverse fields including – advanced manufacturing, aerospace, advanced energy, fluids, heat transfer, design engineering, materials, energy recovery, applied mechanics, nanotechnology, and bioengineering. Lall has previously served as the Congress Steering Committee Chair for the ASME Congress 2012 and 2013, General Chair of the ASME Congress in 2010, and the Technical Program Chair of ASME Congress in 2009.

Lall serves as the General Chair of the IEEE PHM 2015

Professor Lall will serve as the General Chair of the IEEE PHM 2015 Conference to be held in Austin, TX in June 22-25, 2015. The conference focuses on prognostics health management systems for a broad array of electrical and electronic systems with emphasis on principles, system design, implementation, applications.

Selected Recent Publications

1. Lall, P., Lowe, R., Comparison of Prognostic Health Management Algorithms for Assessment of Electronic Reliability Under Vibration, ASME Journal of Electronic Packaging, Volume 136, No. 4, doi:10.1115/1.4028163, pp. 1-8, December 2014.
2. Lall, P., Wei, J., Prediction of L70 Life and Assessment of Color Shift for Solid State Lighting Using Kalman Filter and Extended Kalman Filter Based Models, IEEE Transactions on Device and Materials Reliability, Volume. PP, No.99, doi 10.1109/TDMR.2014.2369859, pp. 1-15, November 2014.
3. Lall, P., Zhang, D., Yadav, V., Locker, D., Measurement of the High Strain Rate Mechanical Behavior of SAC305 Alloy at Product Operating Temperature and Derivation of Anand Viscoplasticity Constants, Proceedings of the SMTAI, Rosemont, IL, pp. 284-292, September 28-October 2, 2014.
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All other published CAVE^3 articles are available at cave.auburn.edu under Publications

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Spring 2015

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