AUBURN UNIVERSITY
SAMUEL GINN
COLLEGE OF ENGINEERING

Fall 2016

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.

Message from Director

Manufacturing is an activity of immense importance to the US economy. Each dollar of value added in manufacturing generates at least an equal amount of value in additional transactions - according to WSJ article published on June 7, 2016, on the topic of US manufacturing. In contrast, professional and business services only result in a $0.36 in additional transactions for each additional dollar spent on services. Thus, manufacturing is vastly more valuable in creating additional transactions than services. Presently, the US economy runs a surplus in services – however, deficit in manufacturing of goods is so large that it more than offsets the surplus from services resulting in a massive trade deficit which has been growing. With the increase in automation, the exports have grown – however the imports have grown faster than the exports fueling the trade deficit. The result is that the US share of manufacturing has declined consistently in the period from 2000 to 2013. Manufacturing related employment was trending lower even before the 2008 recession has been slow to recover with the growth in manufacturing related jobs being nearly flat to none. The national network of manufacturing institutes is initiative which is intended to re-establish the manufacturing ecosystem in the United States. NextFlex is the 7th manufacturing institute established under this initiative in the topical area of flexible electronics. AU is a Tier-1 academic founding member of NextFlex and leads the harsh environments node of the institute. In addition, the center director, Pradeep Lall serves as the academic co-lead of the Asset Monitoring System Technical Working Group. FHE is finding applications in a number of diverse fields encompassing both commercial and military applications. Examples include smart clothing for environment and health monitoring, sensors for biomarkers in sweat, blood oximetry sensors, heart rate and waveform sensors, wearable technologies for fitness information and communication. The integration of FHE in automotive applications is on an upward trend with applications including defoggers, IME consoles, seat heaters, OLED lighting, and OLED displays. The trend toward driverless cars presents additional opportunities for the integration of FHE for camera, radar and LIDAR into the automotive body. Realization of FHE implementation in the diverse fields needs commercialization of flexible hybrid electronics technologies in a number of areas including materials scale-up, thinned die processing, integrated printing, semiconductor packaging, system design tools, and reliability testing. In Project Call 2.0, Topic 2.5, AU led team won the proposal on development of test protocols for flexible hybrid electronics. In this project, the AU led team will develop test methods which can be used for the assessment of expected survivability of FHE in harsh environments. The test methods will focus on FHE technologies under a number of use scenarios in the presence of electrical bias.

Professor Lall Wins the NSF 2016 Alex Schwarzkopf Award for Technological Innovation

Auburn University mechanical engineering professor Pradeep Lall has received a top National Science Foundation award for his work as director of Auburn's Center for Advanced Vehicle and Extreme Environment Electronics, or CAVE3. His research includes developing methods for protecting electronics in harsh environments. Lall, the John and Anne MacFarlane Endowed Professor in Auburn's Department of Mechanical Engineering, was recently awarded the 2016 Alexander Schwarzkopf Prize for Technological Innovation from the National Science Foundation's Industry/University Cooperative Research Centers program. "This award is reaffirmation of Dr. Lall's national reputation and recognition of his seminal contributions to the field of mechanical engineering," said Christopher Roberts, dean of the Samuel Ginn College of Engineering. "His work has positioned Auburn Engineering to be a leader in harsh environment electronics research as we address the challenges in this exciting field." Lall's research focuses on the development of methods for assuring survivability of electronics to high shock forces, vibration and extreme temperatures. He is best known for his research in the areas of reliability and prognostics for electronic systems operating in harsh environments such as: Combined exposure to temperature and vibration under the hood of an automobile for electronics mounted on-engine or on-transmission; Extreme cold or extreme hot environmental temperatures for prolonged periods of time experienced in military and defense applications; High g-forces experienced by electronics inside missiles; Corrosive attack of salt fog for electronics operating on ships at sea. (Continued on Page 6)

CAVE³ Consortium Spring-2016 Technical Review Meeting

The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE³) will hold its Spring Technical Review and Project Planning Meeting on March 7-8, 2016 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 CAVE³ 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

2016 IEEE International Conference on Prognostics and Health Management

June 20-22, 2016
Carleton University,
Ottawa, ON, Canada
Professor Pradeep Lall is served as the General Chair of the 6th Annual IEEE Reliability Society PHM conference will be held June 20-22 at Carleton University, Ottawa, ON, Canada. The conference brought 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 included Tutorials, Panel Sessions, and Papers that address the wide-ranging, interdisciplinary topics related to PHM technology and application. There was a special working session on the in-process development of a PHM Standard. There was a special session with presentations from the most successful entries in the conference PHM Challenge. CAVE3 presented the following paper at the conference:

1. Lall, P., Deshpande, S., Nguyen, L., ANN Based RUL Assessment of Copper-Aluminum Wirebonds Subjected to Harsh Environments, Proceedings of the IEEE PHM Conference, Ottawa, Canada, pp. 1-10, June 20-22, 2016
2. Lall, P., Zhang, H., Prognostication of Remaining Useful Life for Flexible Batteries in Foldable Wearable Electronics, Proceedings of the IEEE PHM Conference, Ottawa, Canada, pp. 1-10, June 20-22, 2016.

SMTA International 2016

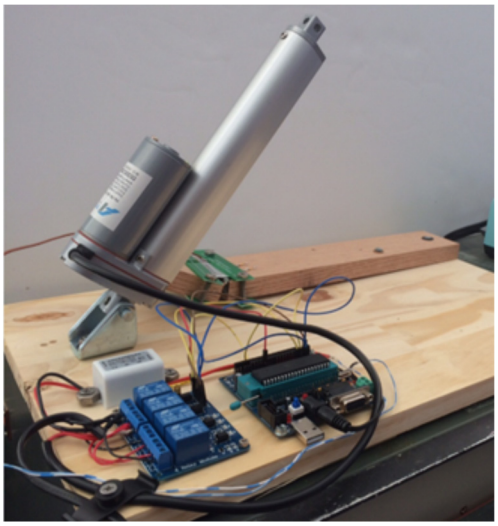
Conference: Sep. 26—Sep. 30, 2016
Exhibition: Sep. 29—Sep. 30, 2016
Donald Stephens Convention Center, Rosemont, IL
Annual SMTA International Conference will be held at the Donald Stephens Convention Center in Rosemont, Illinois from Sept 27-Sept 30, 2016. CAVE3 will be holding the Harsh Environment Symposium as part of the conference. The HE symposium will be held on the first two-days of the conference. The papers will focus on environments including thermal, thermo-mechanical, vibration, mechanical shock, corrosion, and contamination. CAVE3 will be presenting 3-papers at the conference:

1. Survivability Assessment and Life-Modeling of Fine Pitch Solder Joint Fuze Electronics Under Mechanical Shock Loads up to 50,000g
   P. Lall, K. Dornala, J. Foley, J. Deep, R. Lowe, Session HE2, 2016
2. X-ray Micro-CT Based Finite Element Models for Remaining Useful Life Assessment of Field Deployed Electronics , P. Lall, J. Wei, Session HE2, 2016
3. Effect of Alloy Composition and Isothermal Aging on the Survivability of Lead-free Solder Joints in High Temperature and Vibration, Automotive Environments, P. Lall, D. Zhang, V. Yadav, J. Jangula, B. Palmer, R. Kinyanjui, Session HE4, 2016

Research Highlights

Survivability and Remaining Useful Life Assessment of Flexible Batteries in Wearable Electronics

Electronics is increasingly being used in biometric applications for measurement of blood pressure, pulse-ox, heart rate, and biomarkers in sweat. Wearable applications necessitate the use of power sources in thinner form factors which can perform reliably under the stresses of daily motion while being exposed to body temperatures. Power sources may need instantaneous peak power and may be subjected to repeated charge and discharge cycles during the use-life of wearable electronics. In this paper, the state of art thin battery technologies commercially available have been studied for their survivability under exposure to environmental loads typical of wearable electronics applications. In addition, a solution for prognosticating the capacity degradation and remaining useful life have been developed.

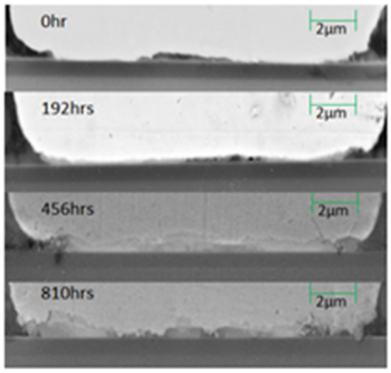


Test Set Replicate Daily Motion on Flexible Battery

The charging and discharging cycles were performed on the flexible battery with a test station. The test station was comprised of a programming source meter, a programmable electronic load and a data logger. All of the test devices were controlled with LabVIEW. The test station also allowed for an input of various charging/ discharging conditions. A 1C CC (constant current) charge and discharge current rate was used in the cycles to accelerate the life test. During the test, flexible batteries were subjected to the thermal stress in an environmental chamber. Once a finite number of cycles had been imposed during the accelerated life test, the battery was cooled down to room temperature. Test results at different temperatures were used to estimate the remaining useful life of the battery using extended kalman filter.

Multiphysics Life-Prediction Model Based On Measurements of Polarization Curves for Copper-Aluminum Intermetallics

Copper wire bonding is finding applications in automotive underhood electronics applications including lane departure warning systems, collision avoidance systems, and vehicle stability systems. The Cu-Al wire bond is susceptible to the corrosion and the reliability of Cu-Al wire bond is of great concern. Typical electronic molding compounds are hydrophilic and absorb moisture when exposed to humid environmental conditions and may contain ionic contaminants including chloride ions as a result of the chemical synthesis of the subcomponents of the resin, etching of metallization, the decomposition of the die-attach, epichlorohydrin in the resin as a flame retardant. The presence of moisture in the operating environment of semiconductor package makes the ion more mobile in the EMC.



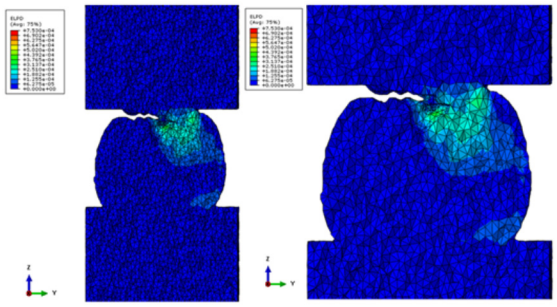
IMC Growth under Isothermal Aging

Models for prediction of the diffusion of the chloride ions and the corrosion of the copper-aluminum interface have been difficult to develop, because of the small scale of the interface and the lack of appropriate electro-chemical properties for the Cu-Al system and the Electronic Molding Compounds under conditions relevant to operation. In this effort, a multiphysics model for galvanic corrosion in the presence of chloride has been presented based on fundamental physics of failure measurements of the corrosion kinetics of Cu, Al, and IMCs. The specific IMCs measured include CuAl, $CuAl_2$, and Cu_9Al_4. The contaminant diffusion along with the corrosion kinetics has been modeled. In addition, contaminated samples with known concentration of KCl contaminant have been subjected to the temperature humidity conditions of 130° C/100RH. Moisture ingress into the EMC has been quantified through measurements of the weight gain in the EMC as a function of time. Tafel parameters including the open circuit potential and the slope of the polarization curve has been measured for both copper, aluminum under different concentrations of the ionic species and pH values in the EMC. The measurements have been incorporated into the COMSOL model to predict the corrosion current at the Cu-Al bond pad and develop acceleration factors for copper-aluminum wirebond corrosion.

Remaining Useful Life Assessment of Field Deployed Electronics Using X-Ray Micro-CT Based Digital Volume Correlation and Finite-Element Analysis

A new method for residual life assessment of field extracted electronic systems using X-ray MicroCT data in conjunction with digital volume correlation (DVC) and finite element analysis (FEA) has been presented. Electronic components deployed in harsh environments may be subjected to significant deformation under the action of thermal and mechanical loads during operation and storage. The use of thin material layers in addition to fine embedded interconnects limits the possibilities for the integration of sensors to measure deformation and strain. In addition, models for semiconductor assemblies are created using nominal dimensions from a material

datasheet. However, the use of nominal dimensions does not account for the dimensional variabilities of the geometry due to process-variance in the manufacturing process window.



Total energy dissipated in the element by deformation

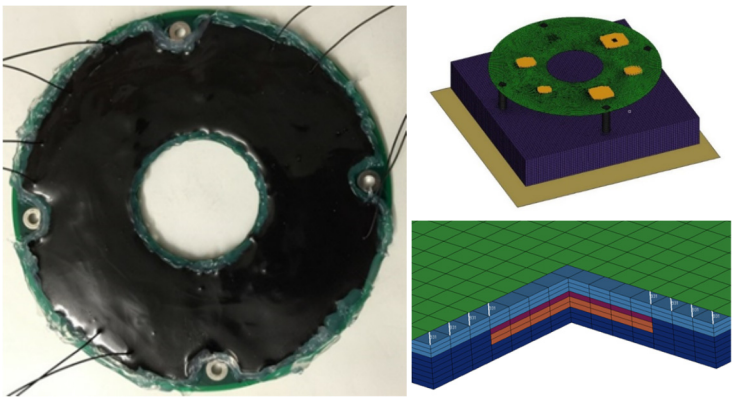
In this paper, a new method has been presented for measurement of displacements and assessment of remaining useful-life in solder joints non-invasively using a combination of X-ray computed tomography, DVC and FEA. The new method does not require cross-sectioning of the part for the purpose of deformation and strain measurement. In addition, the measurements are not limited to the joints in the line of sight. The three-dimensional measurements of deformation and strain have been visualized on the geometry of the solder joints in the package. Furthermore, the X-ray MicroCT grayscale data has been ported into a finite element platform. Anand Viscoplasticity model of SAC305 has been utilized and merged into the FEA software to model material behavior of solder interconnects. The method has been applied to a field extracted assembly for analysis of residual life of solder joints with partial cracks in cyclic thermal environments. The cumulative plastic work and stress-strain hysteresis loop have been plotted.

Life Prediction and RUL Assessment of Fine Pitch Solder Joint Fuze Electronics Under Mechanical Shock Loads Up To 50,000g

Reduced size and geometry constraints imposed on electronics in various harsh environment applications has motivated a tremendous demand for use of very fine pitch surface mount electronics. Fine pitch BGAs of 0.4mm and 0.5mm pitch are finding applications in military and defense applications. Fine pitch BGA electronics used in fuzing for aerospace projectile applications they may be subjected to high-g levels in the neighborhood of 10,000g-50,000g of mechanical shock during normal operation. Commercial-off-the-Shelf (COTS) parts are increasingly being used for military and defense applications. Survivability of electronics in consumer applications is often ascertained using the JEDEC Test Standard JESD22-B111. The test standard prescribes the application of a 1500g, 0.5ms shock pulse to the board assembly. Survivability and design envelope of fine pitch semiconductor packages under high-g mechanical shock in the range of 10,000g-50,000g of mechanical shock is unknown.

Test Vehicle-STYCAST 2850FT epoxy potted and underfilled

In addition, the efficacy of the traditional supplemental restraint mechanisms such as underfills in mitigating the risk of interconnect



failure under high-g mechanical shock, is not available. In this study, instead of using a JEDEC form-factor board, a product form-factor circular board with an annular ring typical of projectile applications has been designed with fine pitch daisy chained packages. Packages studied have package interconnects in the range of 84-360 I/O. Three configurations of the test board have been studied including non-underfilled, underfilled assemblies, and potted assemblies. Two categories of underfills has been used including Lord Thermoset ME-531, and Loctite UF 3811. Two categories of potting compounds have been used including Armstrong A12, Henkel Stycast 2850FT. Armstrong A12 is a low modulus material and Henkel Stycast 2850FT is a high modulus material intended for shock applications.

PCR Model for Prediction of Acceleration Factors for Copper-Aluminum Wirebonds Subjected to Harsh Environments

In this paper, predictive model for acceleration factor of copper based on PCR approach is presented. A set of parts, molded with different EMC's were subjected to high temperature environment (150°C-225°C). Resistance, IMC change and shear strength change were monitored during this study. Resistance spectroscopy was used for accurate resistance measurement. Dage 2400PC was used to calculate change in shear strength. Parts were cross-sectioned and polished along Cu-Al interface using SEM and EDX system after failure. Relation between resistance changes with change in shear strength was established. 20% change in resistance was considered as failure threshold. All parts were tested till failure. Time-to-failure data was used to calculate acceleration factor, with 150°C as a base temperature. Different AF's obtained for different EMC's were then regressed against environmental conditions, mechanical and chemical properties of molding compound. All packages had same architecture, wire diameter and pad thickness. Principal component analysis was used to identify influential variables and to remove multi-collinearity in the data set.

Announcements

CAVE3 Paper wins the Best of IEEE Transactions on Components, Packaging and Manufacturing Technology

The following CAVE3 paper won the best paper of the IEEE Transactions on Components, Packaging and Manufacturing Technology – Electronics Manufacturing Category. The research presented in the paper was funded by a TI-customized SRC contract. The award was presented at the IEEE Electronics Components and Technology Conference in Las Vegas, NV.

> *Lall, P., Patel, K., Narayan, K., Model for Inverse Determination of Process and Material Parameters for Control of Package-on-Package Warpage, IEEE Transactions on Components, Packaging and Manufacturing Technology, Volume 5, No. 9., pp. 1358 – 1375, Sept 2015.*

Co-authors Kewal Patel and Vikalp Narayan are MS students who worked under the guidance of Professor Pradeep Lall. Kewal is now employed at Harris Corporation. Vikalp now works for San Disk.

Auburn University Researcher wins National Science Foundation Award for Technological Innovation
(Continued from Page-1)
"Electronic systems have taken an increasingly important role in automotive design and operation," Lall said. "Traditional auto-

motive electronics at one time consisted of climate control and entertainment systems. Roll the clock forward to the present day and automotive electronics have expanded to include driving assists such as antilock braking systems, traction control systems, adaptive cruise control, lane departure warning systems and more. Failure of one of these systems is no longer an inconvenience; it may be critical to the safe operation of the vehicle."

Founded in 1999 as the Center for Advanced Vehicle Electronics, CAVE3 has over the years expanded its expertise to include extreme environment electronics. Lall has been the center's director since 2008, following his appointment as associate director in 2004. Lall also directs Auburn's Harsh Environments Node of the NextFlex Manufacturing Institute, part of a national manufacturing effort on harsh environment electronics led by the U.S. Department of Defense. CAVE3 partners with industry, government and academic agencies to address major technological challenges through precompetitive research on automotive and harsh environment electronics. This arrangement gives the center an opportunity to address the challenges before the technologies become commercialized.

Lall joined the Auburn faculty in 2002 after a distinguished industry career at Motorola, where he worked on the development and manufacture of wireless products such as cellphones and two-way radios. "Dr. Lall's recognition with the Alex Schwarzkopf Prize is evidence of the societal and transformational impact that Auburn University is making on automotive and harsh environment technologies in everyday life," said John Mason, Auburn's vice president for research and economic development.

The National Science Foundation's cooperative research centers program was established in 1973 by Schwarzkopf to develop long-term research partnerships among industry, academe and government in areas of mutual interest. The Alexander Schwarzkopf Prize for Technological Innovation has been presented annually since 2003 to an individual or team at a member institution whose research makes an exemplary contribution to technology innovation. More than 100 universities and nearly a thousand researchers are members.

CAVE3 to Co-Chair the Harsh Environments Workshop at the SMTAI 2016
Professor John Evans (AU), Prof. Pradeep Lall (AU) and Dr. Robert Kinyanjui (JDES) will co-chair the harsh environment symposium at the SMTAI 2016 conference in Rosemont, Illinois on Sept 26, 2016. CAVE3 will be presenting two papers at the conference.

Lall elected VP of Publications of the IEEE Reliability Society
Professor Lall has been elected as Vice-President of Publications of the IEEE Reliability Society. In this role he will be involved with the IEEE Reliability Society publications including the IEEE Transactions on Reliability (TREL), Transactions on Semiconductor Manufacturing (TSM), and Transactions for Device and Materials Reliability (TDMR).

CAVE3 Researchers win the Outstanding Paper at the ITHERM 2016 in Las Vegas

The following paper won the Outstanding Poster Paper of the Mechanics-Track in the ITHERM Conference held in Las Vegas, NV from May 31-June 3, 2016:

> Lall, P., Yadav, V., Suhling, J., Locker, D., High Strain Rate Stress-Strain Measurement of SAC105 Leadfree Alloy at Temperatures up to 200C, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 1225- 1236, May 31- June 3, 2016.

A number of CAVE3 students traveled to the ITHERM 2016 conference to present their research.

Selected Recent Publications

1. Lall, P., Luo, Y., Nguyen, L., Multiphysics Life-Prediction Model Based on Measurement of Polarization Curves for Copper-Aluminum Intermetallics, Proceedings of the 66th ECTC, Las Vegas, Nevada, pp. 1027- 1039, May 31- June 3, 2016
2. Lall, P., Wei, J., Remaining Useful Life Assessment of Field Deployed Electronics Using X-ray Micro-CT Based Digital Volume Correlation and Finite- Element Analysis, Proceedings of the 66th ECTC, Las Vegas, Nevada, pp. 1583- 1593, May 31 - June 3, 2016
3. Lall, P., Deshpande S., Nguyen, L., Principal Components Regression Model for Prediction of Acceleration Factors for Copper- Aluminum Wirebonds Subjected to Harsh Environments, Proceedings of the 66th ECTC, Las Vegas, Nevada, pp. 637- 648, May 31- June 3, 2016
4. Lall, P., Dornala K., Suhling, J., Lowe, R., Foley, J., Life Prediction and RUL Assessment of Fine Pitch Solder Joint Fuze Electronics Under Mechanical Shock Loads Up To 50,000g, Proceedings of the 66th ECTC, Las Vegas, Nevada, pp. 232- 244, May 31- June 3, 2016
5. Lall, P., Zhang, D., Yadav, V., Suhling, J., Locker, D., Effect of Temperature on the High Strain Rate Properties of SAC Lead-free Alloys at Temperatures Up to 200C, Proceedings of the 66th ECTC, Las Vegas, Nevada, pp. 1924- 1933, May 31- June 3, 2016
6. Nguyen, Q., Roberts, J., Suhling, J., Jaeger, R., Lall, P., Characterization of Moisture Induced Die Stresses in Flip Chip Packaging, Proceedings of the 66th ECTC, Las Vegas, Nevada, pp. 789- 799, May 31- June 3, 2016
7. Fu, N., Suhling, J., Lall, P., Cyclic Stress- Strain Behavior of SAC305 Lead Free Solder: Effects of Aging, Temperature, Strain Rate, and Plastic Strain Range, Proceedings of the 66th ECTC, Las Vegas, Nevada, pp. 1119- 1128, May 31- June 3, 2016
8. Lall, P., Sakalaukus, P., Davis, L., Improvements to the IES TM -28-14 Lumen Maintenance Standard: A Generalized Acceleration Factor Approach for Solid-State Lighting, Proceedings of the 66th ECTC, Las Vegas, Nevada, pp. 1342- 1352, May 31- June 3, 2016
9. Lall, P., Abrol, A., Simpson, L., Glover, J., A Study of Damage Progression in MEMS Based Silicon Oscillators Subjected to High-G, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 546-560, May 31- June 3, 2016
10. Lall, P., Kothari, N., Foley, J., Deep, J., Lowe, R., A Novel Micro-CT Based Finite Element Modeling Technique to Study Reliability of Densely Packed Fuze Assemblies, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 456- 464, May 31- June 3, 2016
11. Lall, P., Yadav, V., Suhling, J., Locker, D., High Strain Rate Stress-Strain Measurement of SAC105 Leadfree Alloy at Temperatures up to 200C, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 1225- 1236, May 31- June 3, 2016
12. Lall, P., Luo, Y., Nguyen, L., De-Bonding Simulation of Cu-Al Wire Bond Intermetallic Compound Layers, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 862-871, May 31- June 3, 2016
13. Lall, P., Zhang, H., Davis, L., A Comparison of Temperature and Humidity Effects on Phosphor Converted LED Package and the Prediction of Remaining Useful Life with State Estimation, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 207- 217, May 31- June 3, 2016
14. Lall, P., Wei, J., PBGA Package Finite Element Analysis Based on the Physical Geometry Modeling Using X-ray Micro-CT Digital Volume Reconstruction, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 285- 295, May 31- June 3, 2016
15. Lall, P., Deshpande, S., Nguyen, L., Prognostication of Cu-Al WB System Subjected to High Temperature-Humidity Condition, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 887- 898, May 31- June 3, 2016
16. Lall, P., Dornala, K., Lowe, R., Foley, J., Survivability Assessment of Electronics Subjected to Mechanical Shock Up to 25,000g, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 507- 519, May 31- June 3, 2016
17. Lall, P., Mirza, K., Suhling, J., A Study on the Effect of Aging on Thermal Cycling Reliability of Sn-Ag-Cu Interconnects Using Digital Image Correlation, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 519- 530, May 31- June 3, 2016
18. Roberts, J., Bhat, C., Suhling, J., Jaeger, R., Lall, P., Reliability of a CBGA Microprocessor Package Incorporating a Decoupling Capacitor Array, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 278- 285, May 31- June 3, 2016
19. Basit, M., Ahmed, S., Motalab, M., Roberts, J., Suhling, J., Lall, P., The Anand Parameters for SAC Solders after Extreme Aging, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 440- 448, May 31- June 3, 2016
20. Chen, C., Suhling, J., Lall, P., Improved Meshing Strategy for Finite Element Modeling of PBGA Thermal Cycling, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 448- 456, May 31- June 3, 2016
21. Motalab, M., Mustafa, M., Suhling, J., Lall, P., Improved Predictions of Cyclic Stress-Strain Curves for Lead Free Solders Using the Anand Visocplastic Constitutive Model, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 471- 481, May 31- June 3, 2016
22. Fu, N., Suhling, J., Mustafa, M., Lall, P., Aging Induced Evolution of the Cyclic Stress-Strain Behavior of Lead Free Solders, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 737- 746, May 31- June 3, 2016
23. Ahmed, S., Basit, M., Suhling, J., Lall, P., Effects of Aging on SAC-Bi Solder Material, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 746- 755, May 31- June 3, 2016
24. Alam, M., Basit, M., Suhling, J., Lall, P., Mechanical Characterization of SAC305 Lead Free Solder at High Temperatures, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 755- 761, May 31- June 3, 2016
25. Chowdhury, M., Ahmed, S., Fahim, A., Suhling, J., Lall, P., Mechanical Characterization of Doped SAC Solder Materials at High Temperature, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 1202- 1209, May 31- June 3, 2016
26. Fahim, A., Ahmed, S., Chowdhury, M., Suhling, J., Lall, P., High Temperature Creep Response of Lead Free Solders, Proceedings of the ITHERM 2016, Las Vegas, Nevada, pp. 1218- 1225, May 31- June 3, 2016
27. Lall, P., Deshpande, S., Nguyen, L., ANN Based RUL Assessment of Copper-Aluminum Wirebonds Subjected to Harsh Environments, Proceedings of the IEEE PHM Conference, Ottawa, Canada, pp. 1-10, June 20-22, 2016
28. Lall, P., Zhang, H., Prognostication of Remaining Useful Life for Flexible Batteries in Foldable Wearable Electronics, Pro-

Selected Recent Publications

ceedings of the IEEE PHM Conference, Ottawa, Canada, pp. 1-10, June 20-22, 2016.

All other published CAVE³ articles are available at cave.auburn.edu under Publications

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