AUBURN UNIVERSITY
SAMUEL GINN
COLLEGE OF ENGINEERING

Fall 2018

cave³ News

NSF-CAVE3 Electronics Research Center
cave.auburn.edu; PH: (334) 844-3424

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

We have had a busy summer !! CAVE3 Students and Faculty attended the IRPS, ECTC and ITHERM conferences with strong showing in presented technical papers, professional development course and panels. We attended and presented papers at the IRPS in San Francisco, CA. I gave an invited talk on the topic of "Prognostics Health Management of Electronic Systems – A Reliability Physics Approach" in the system reliability track. CAVE3 won top honors at the ITHERM 2018. Our papers on "A Novel Numerical Multiphysics Framework for the Modeling of Cu-Al Wire Bond Corrosion under HAST Conditions" won the outstanding paper in the oral-session and "Flexible Power-Source Survivability Assurance under Bending Loads and Operating Temperatures Representative of Stresses of Daily Motion" won the outstanding paper in the poster-session at the ITHERM 2018.

Earlier in August, CAVE3 presented at the NextFlex Innovation Day. Auburn University is a tier-1 founding member of the NextFlex Manufacturing Institute. We have been a regular exhibitor at the NextFlex Innovation Day since the establishment of the institute. This year was no exception. The NSF-CAVE3 Electronics Packaging Research Center exhibit was one of the featured booths at the NextFlex Innovation Day held in San Jose on Aug 9th. Our team was presenting the biometric band developed for remote worker monitoring in addition to experimental protocols for flexing, folding, and stretching developed for flexible printed electronics. Our booth was one of the featured exhibits during the show and was interviewed by a number of media outlets.

The Biometric Band device will be used for remote monitoring of the workers in hazardous environments and for the monitoring of elderly patients who need continual medical oversight. It is used by wearing on the hand and pairing to a cellular smartphone. For example, majority of the tasks surrounding the inspection of aircraft fuel tanks and the associated systems must be done in the interior of the tanks. On commercial aircraft, the fuel tanks may be located in both the fuselage and the wing of the aircraft. The multi-sensor bio-medical band will be worn by the operator working in a confined space. The band has multiple sensors including – GPS, pulse-ox, pulse-rate, and electromyography sensor for measurement of the loss of blood oxygenation resulting from depletion of oxygen in the environment in the fuel tank, abrupt changes in the pulse rate resulting from anxiety or claustrophobia, loss of consciousness, myocardial infarction, stroke, bradycardia or aneurysm. It is possible to have continual medical oversight over the vital functions in a hospital setting with the user tethered to the bed and monitoring equipment. However, this is not possible outside the ICU. The differentiator in the present solution is that it allows for remote monitoring without the use of wires or tethers to tie down the user.

The emergence of additive printed flexible electronics has been exciting for the industry and particularly for CAVE3. In addition to the semi-automatic and fully automated surface mount line, we have aerosol-jet and screen-printed electronics capabilities. This coupled with Micro-Computed Tomography capabilities allows for a full range of topical areas from design, fabrication, manufacturing process and reliability of new packaging architectures. Presently, there are a number of programs ongoing for development of process parameters for printing of metallization, interconnects and dielectrics on both planar and non-planar surfaces.

The CAVE3 center, which has always had a stable membership base, has experienced strong growth. I also want to welcome ARDEC and AMAZON to the Center this Fall-Review.

Pradeep Lall,
John and Anne MacFarlane Professor and Director

CAVE3 Consortium Fall-2018 Technical Review Meeting

The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE³) will hold its Fall Technical Review and Project Planning Meeting on September 5-6, 2018 in Auburn University Wiggins Hall. All current members of the Consortium are invited to attend. The following projects will be presented at the meeting:

- Effect of Shallow Cycling on Flexible Power-Source Survivability under Bending Loads and Operating Temperatures Representative of Stresses of Daily Motion
- Reliability of Flexible Substrates Under Stresses of Daily Motion
- Measurement of Interfacial Fracture Toughness and Cohesive-Zone Models of Potting Compounds with FR4 PCBs
- High-G Shock Reliability of Micro-Coil Springs and Polymer Core Ball Interconnects
- Reliability of SAC 305 Solder Interconnects on Double-Sided Flexible Printed Circuit Board Using X-Ray Micro-CT
- Design of Biometric Band and LifeSaver APP in Wear-and-Forget Format
- Reliability of a Fuze Assembly Using Micro-CT data based FE and Digital Volume Correlation
- Characterization of Electrical and Mechanical material properties using Aerosol Jet Printing based Additive Manufacturing Process
- Prognostication of Electronic Assemblies Subjected to Temperature-Vibration Loads
- Sub-Modeling of SJ Reliability in High-Temperature Vibration
- High Strain Rate Properties of SACQ Solder after Prolonged Thermal Aging up to 6-Months
- Damage evolution in MEMS Pressure Sensors during High Temperature Operating Life and Prolonged Storage at Sub-Zero Temperature
- Effect of High Temperature on Reliability of Cu, Au, Ag, PCC WB
- Moving Boundary Model based on the electrochemical measurements of Cu and Cu-Al IMCs
- Effect of Mean Temperature on The Evolution of Strain Amplitude in SAC Ball Grid Arrays During Operation under Thermal Aging and Temperature Excursions
- Mechanical Characterization of Solder Mask Materials
- Characterization of Die Stresses in Plastic Ball Grid Array Packages Subjected to Various Moisture Conditions
- Improved Finite Element Simulation Strategy with Submodeling for BGA Packages Subjected to Thermal Cycling
- The Effects of Temperature, Strain Rate, and Aging on The Poisson's Ratio of SAC Lead Free Solders
- Reliability of Aged Lead Free Doped Solders For Temperature Accelerated Life Testing
- Reliability Analysis of Super Ball Grid Array Packages
- Effect of Surface Finish on the Shear and Fatigue of Lead-Free Doped Solder Joints
- Evolution of the Cyclic Stress-Strain Behavior of Doped SAC Solder Materials Subjected to Isothermal Aging
- Evolution of the Cyclic Stress-Strain and Constitutive Behaviors of Doped Lead Free Solder During Fatigue Testing
- Effects of Mechanical Cycling on the Microstructure of Lead Free Solders
- Mechanical Characterization of SAC Solder Joints at High Temperature Using Nanoindentation
- Nanoindentation Measurements of the Mechanical Properties of Individual Phases Within Lead Free Solder Joints Subjected to Isothermal Aging
- Effects of High Temperature Aging on The Mechanical Behavior of Lead Free Solders
- A Comparative Study of the High Temperature Mechanical Behavior of SAC and SAC+X Lead Free Solders
- Investigation of Aging Induced Evolution of the Microstructure of SAC305 Lead Free Solder
- Evaluation of Aging Induced Microstructural Evolution in Lead Free Solders Using Scanning Probe Microscopy

Contact Information:
1418 Wiggins Hall, Department of Mechanical Engineering
Auburn University, Auburn, AL
Call: (334) 844-3424

SPECIAL EVENTS

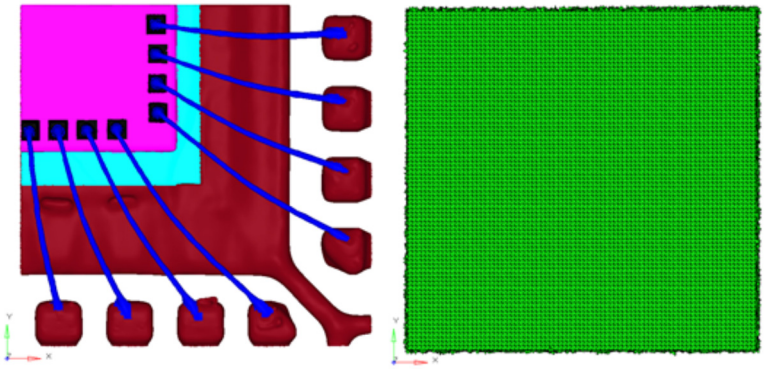
SMTA International 2018

Conference: Oct. 14—Oct. 18, 2018
Donald Stephens Convention Center, Rosemont, IL

CAVE3 will be again heading the Harsh Environment Track at the SMTA International Conference this year. The Track started as a separate CAVE3/SMTA Harsh Environment Workshop in 2003 and merged with the main SMTA International Conference later after experiencing growth. The 2018 program has 4-sessions in the topical area of harsh environments. Annual SMTA International Conference will be held at the Donald Stephens Convention Center in Rosemont, Illinois from Oct. 14— Oct. 18, 2018. Professor Lall is member of the SMTA International Technical Advisory Committee and a track co-chair of the Advanced Packaging Technologies track. Professor Hamasha is track co-chair of the Harsh Environments Track. The papers will focus on environments including thermal, thermo-mechanical, vibration, mechanical shock, corrosion, and contamination. Papers on variety of topics such as advanced packaging, assembly process and materials, MEMS, harsh environment, flexible electronics etc. will be presented during this conference. 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

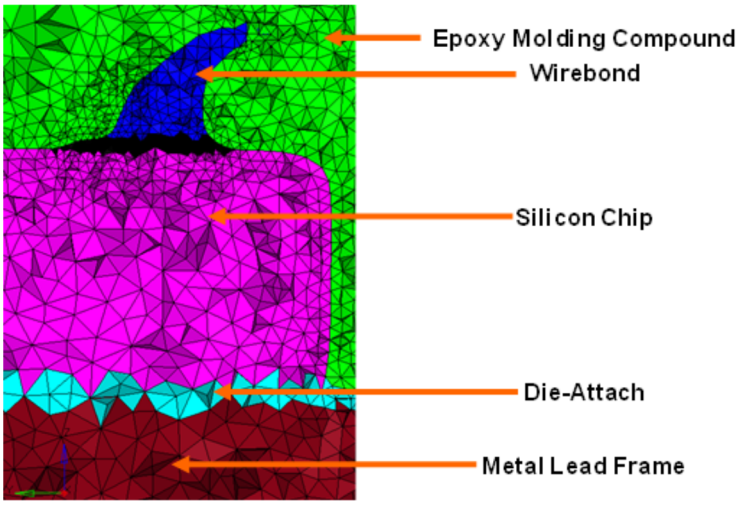
Effect of Green EMCs on Fatigue Reliability of Molded Cu Wirebond System

Replacement of gold (Au) wires by copper (Cu) wires is being widely studied owing to the advantages of copper over gold. Researchers in the past have correlated reliability issues in the Cu wirebonds with higher ionic contamination in the epoxy molding compound (EMCs). New EMCs with 5ppm contamination or less are being developed to address this issue. Green EMCs often have very high filler content which reduces coefficient of thermal expansion (CTE) and increases the modulus (E) of EMC. Higher CTE mismatch between EMC and Cu wires can cause accelerated fatigue failures. In this paper, a novel approach is presented to address this issue. Quad flat no leads (QFN) packages bonded with Cu wires were molded with variety of EMCs. The parts then were scanned using X-ray CT system and the scanned data was converted into FE platform. This 3D model includes all the details and represents true geometry of the package. Thermal cycling analysis was performed on the packages to study effect of different EMCs on the reliability of Cu wirebonds. Plastic equivalent strain (εp) was extracted in each case to assess the damage accumulated on the critical wire due to thermal loading. The new methodology presented in the paper allows true assessment of the accrued damage using the true 3D geometry. In this work, 32 pin QFN assembly was scanned using X-ray-CT system and the scanned data was used to build FE model. Different image processing techniques were used during the conversion. Dimensional and geometric accuracy of each component from the model was validated. Individual components were then assembled to create meshed quarter model. The model was free from contact elements or multipoint constrain. Six different EMCs were used for this analysis ranging from low CTE green mold compounds

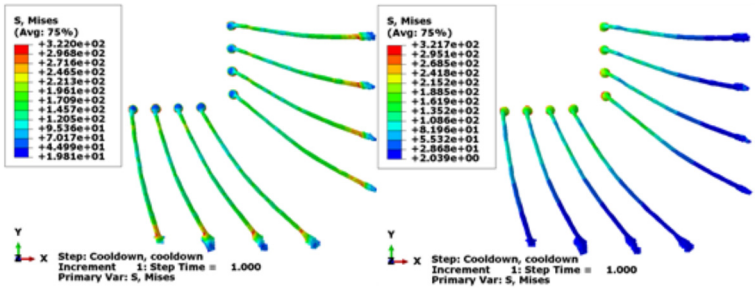


Final 3D model of 32 pin QFN (a) top view (b) bottom view

to high CTE traditional EMCs. Thermal cyclic loading was applied on the package as per AEC-Q100 standard for grade 0 parts. Low CTE EMCs reduces residual stresses on the chip surface but resulted into higher stresses at the lead-frame-EMC interface and in the copper contributed to the CTE mismatch between copper and Si Chip. The residual stresses and plastic strains were concentrated along the wedge bond and were maximum for wires located at the corner of the package. As the CTE of EMC increased, damage at the wedge bond reduced and was nonexistent for EMC D-F. It was concluded that wedge bonds are the critical area in the Cu wire and will fail first. The results reported in this work are consistent with experimental findings reported by prior researchers.



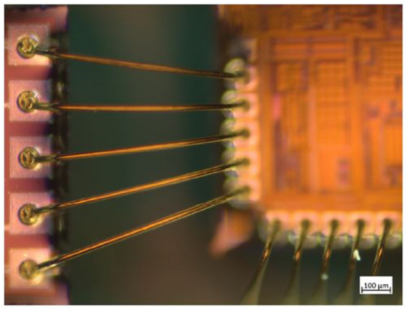
Section view of wirebond, chip and lead frame



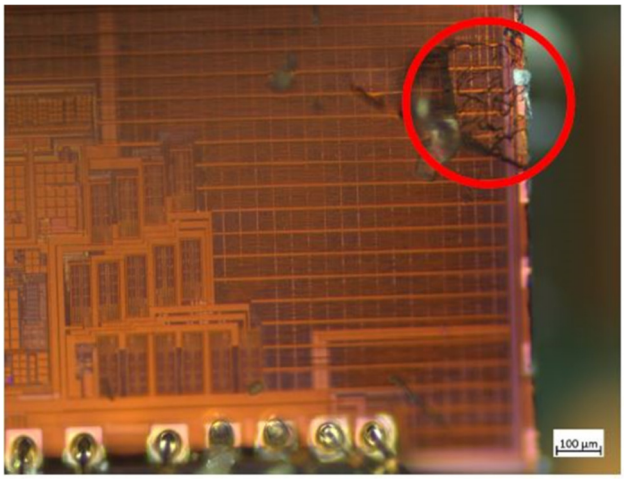
Von Mises stresses during cooling step on the wirebond (a) EMC A (b) EMC F

Damage Evolution in MEMS Pressure Sensors during HTOL and Storage at Sub-Zero Temperature

MEMS Pressure Sensors in harsh environment applications may be subjected to high-temperature operation and prolonged storage at sub-zero temperatures. The adverse effects of thermal and mechanical stresses on MEMS devices are known, but the damage progression through the lifetime of a MEMS device while operating under harsh environmental conditions has not been quantified.



Wire bonds connecting ASIC die to sensing element

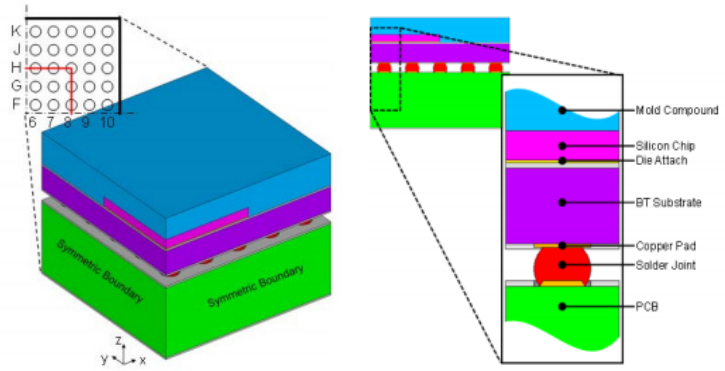


HTOL sample with burn-crack site on ASIC after 210 days of aging at 125°C/3.3Volts

Little to no information exists on incremental deterioration data for commercial MEMS pressure sensors under low temperature storage (LTS) conditions at -35°C and high temperature operating life (HTOL) at 125°C. Not much effort has been made in gathering the attributes of MEMS pressure sensors subjected to high temperature operating life and effect of extreme sub-zero storage conditions. Data on reliability of the devices is needed under conditions similar to their operating field environment in order to document the incremental damage, identify the potential failure sites and provide reasonable solutions for an effective design. In this research study, the effects of high temperature operating life and low temperature storage conditions have been characterized for MEMS pressure sensors. MPL3115a2 is a commercially available MEMS pressure sensor. Sub -zero storage condition of -35oC and high temperature operating life at 125oC, 3.3V have been applied to the MEMS pressure sensor. The pressure sensor test samples have been subjected to a low vacuum at 640mmhg, which falls within the full scale range of the MEMS device, in order to measure the output pressure. The focus of the study is to measure any incremental shift and deterioration in parameters such as absolute pressure and offset of the pressure sensor.

Improved Sub-modeling FE Simulation Strategies for BGA Packages Subjected to Thermal Cycling

The finite element method has been widely used to enable fatigue life predictions for electronic assemblies subjected to thermal cycling. The potential critical region of interest within a solder joint is relatively small relative to the entire package assembly. High-density meshes are typically used to build a package model when using traditional FE modeling approaches. Therefore, long computational times can be expected for an analysis involving several thermal cycles. In order to reduce the complexity of the model and the use of oversize elements, and improve the efficiency of calculation, the technique of global/local modeling (submodeling) has been developed. In this approach, interpolated displacements from coarse model (global model) are applied as boundary conditions to a refined model (local/ submodel) of the critical area of interest. The accuracy and efficiency of submodeling finite element simulations for electronic packages have not been evaluated completely in the literature. In this work, submodeling approaches for BGA assemblies have been explored in detail. A typical BGA package assembly was modeled using several coarse meshes as global models; and the maximum aspect ratio within the global model was varied up to 25, which is near the warning limit of many commercial finite element codes.



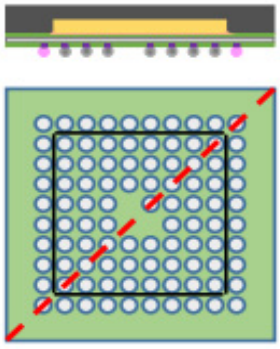
Quarter Assembly Model *Detail View of Example Model*

Once the critical solder joint was identified, then the local model was built using the technique of cut boundaries, and meshed with refined elements. The maximum aspect ratio was also reduced to 5. The simulation result shows the accuracy of solution was sensitive to the mesh quality of the local model, as well as the load step size for both global and local models. An improved simulation strategy using submodeling was developed to obtain the best compromise in the global and local models between the mesh quality and load step size. Although the submodeling is a powerful tool for a better solution in a local region of interest far away from the cut boundaries, it is still crucial to identify the critical region correctly from the global model or a misguided local solution might be performed. Initially, the global models were built using coarse meshes with nonlinear material properties as seen in literature, and then an improved geometric simplification of the solder joint incorporating energy based fatigue criteria was developed. In addition, minimization of the local model volume is still required for a detail analysis of a complex configuration in local region where a high-density mesh is needed. In the investigated approach, we determined the minimized height of the local boundary, and have shown the influence between the height and the solution of volume averaged inelastic strain energy dissipation in the local model. The proposed approach achieves a large reduction in computational time, better detailed modeling of local interest region, and improved simulation accuracy.

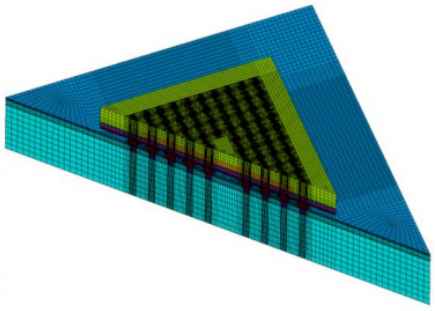
Influence of Poisson's Ratio on the Reliability of SAC Lead Free Solder Joints

In this study, we have conducted a combined numerical and experimental study on the Poisson's ratio of SAC lead free solders. The Poisson's ratio (PR) is one of the basic mechanical properties used in many material constitutive models. Although often not measured, it is important property in many finite element method (FEM) calculations. The value of the Poisson's ratio of SAC lead free solders is relatively unexplored compared to other material properties, and for FEA simulations it is typically assumed to be $\nu = 0.3$. In the current work, we have shown the effects of the chosen value of the solder joint Poisson's ratio on the finite element results for BGA components subjected to thermal cycling. In the finite element mod-

els, the reliability predictions were based on the Morrow-Darveaux energy-based fatigue model. Several sizes (5, 10, 15 mm) of PBGA components with SAC305 solder joints with 0.4 and 0.8 mm spacing were modeled. The packages were subjected to a time dependent cyclic temperature distribution from -40 to 125°C. The package assemblies were assumed to be in a stress-free state at 25°C (room temperature), with no residual stresses induced in the manufacturing process. The simulation results have demonstrated that for specified range of Poisson's ratio values of $0.15 < \nu < 0.40$, the solder Plastic Work varied over 20% and the Predicted Reliability Varied over 50%. To determine the actual Poisson's ratio experimentally, uniaxial tensile stress-strain tests were carried out on SAC305 (96.5Sn3.0Ag0.5Cu) and SAC405 (95.5Sn4.0Ag0.5Cu) specimens using a micro tension/torsion testing machine with two strain rates (0.0001, and 0.00001 (1/sec)) and four testing temperatures (T = 25, 50, 75, 100°C). Deformations and strains in axial and transverse directions were measured using strain gages with automatic data acquisition from LabVIEW software. The recorded transverse strain vs. axial strain data were then fit with a linear regression analysis to determine the Poisson's ratio value. A test matrix of experiments was developed to study the effects of temperature, strain rate, alloy composition, and solidification cooling profile on the value of solder Poisson's ratio. The Poisson's ratio was found to increase with increasing temperature, and decrease with increasing strain rate. With increased silver content, SAC405 was found to have lower Poisson's ratio than SAC305. Finally, using a slower solidification cooling profile led to an increase in the solder Poisson's ratio value. .



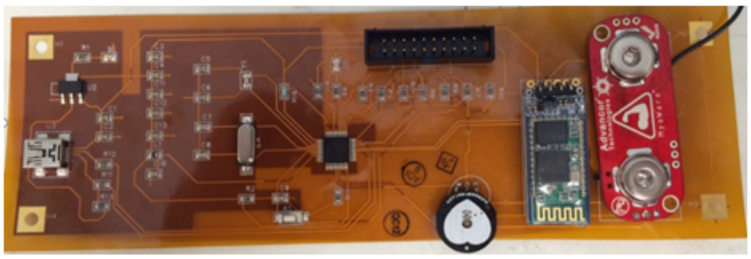
5 mm BGA



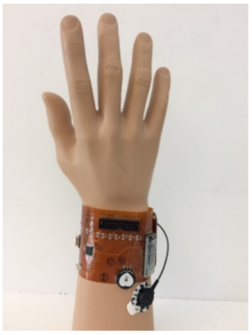
Finite Element Mesh (5 mm BGA)

Novel Flexible Bioelectronics Device and Software Application for Prevention of Sudden Causes of Death

Reducing paramedic response times to five minutes could nearly double survival rates of patients experiencing life-threatening medical conditions. Maintenance of an independent lifestyle with a comparable level of monitoring requires the development of devices, which can provide continuous monitoring and timely medical intervention when needed, without the tie-down constraints of a hospital setting. In this project, a novel rapid-response flexible wearable bioelectronics device has been developed to allow for measurement of vital signals of a patient outside of a hospital setting. A prototype of the device has been fabricated and an android platform based application developed for the implementation of the system. This device monitors sudden changes in biometric information, such as pulse and muscle activity in users and connects to an android phone via a Bluetooth module to call 911 if necessary. The device is intended to decrease paramedic response time during emergencies as well as decrease the percentage of victims of sudden causes of death. Wearable electronics need flexible power sources for running them, in addition to being able to survive the stresses of daily motion during operation. The structural flexibility of the design allows for integration into wear and forget applications.



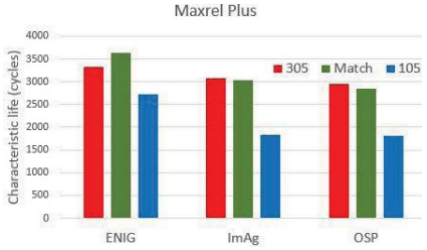
Finished Bioelectronics Device



Battery Package

Effect of Solder Sphere Alloys and Surface Finishes on the Reliability of Lead-Free Solder Joints

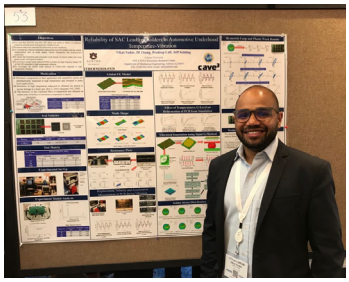
The electronics industry has been moving towards lead-free solders since 2006; Sn96.5 Ag3.0 Cu0.5 (SAC305) and Sn96.5 Agl.0 Cu0.5 (SAC105) have been the popular solder alloys in the industry. The reliability of such alloys is an issue for thermal applications in long-term use. In this paper, the effect of different combination of solder pastes, solder sphere alloys and surface finishes are studied. The test vehicle consists of 15mm and 6mm Ball Grid Array (BGA) components, 5mm Quad Flat No-lead (QFN) packages and 2512 Surface Mount Resistors (SMR). The test vehicles were assembled using different solder pastes onto a 6 layer printed circuit hoards. The boards are isothermally aged hoards at 125°C for 12 months are thermally cycled between -40°C to +125°C. Since there were not many failures for 6mm BGAs QFNs and SMRs, only data regarding 15mm BGAs were used in the study. Two-parameter Weibull analysis is used to analyze the failure data and observe the life degradation of the solder joints based on different factors such as solder pastes solder sphere alloys and surface finishes. It was observed that in most cases, the same surface finish and the same solder sphere alloy performed better than others.



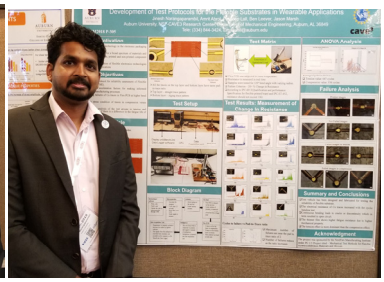
Announcements

Students from Auburn University at the ITHERM 2018 Conference at San Diego, CA

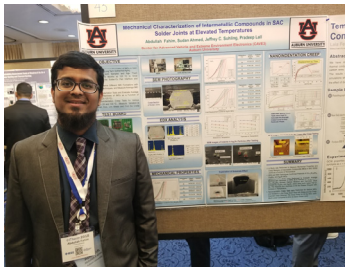
The students attended the ECTC2018 and ITHERM2018 conference from May 29-June1, 2018 in San Diego, CA. CAVE3 Students won top-awards for their papers and presentations. Overall 40+ papers were presented by CAVE3 Researchers. Presentations included in both oral-sessions and poster presentations. A list of the technical papers presented is included in the technical publications of the newsletter.



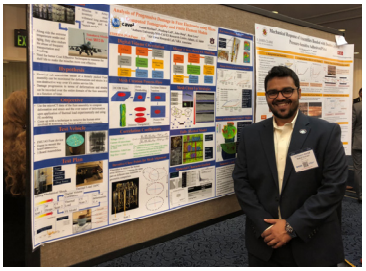
Vikas Yadav



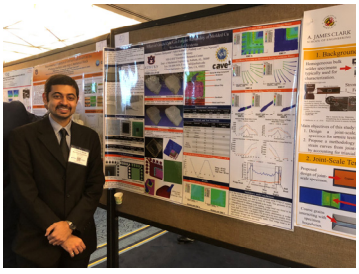
Jinesh Narangaparambil



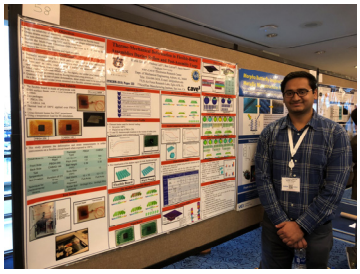
Abdullah Fahim



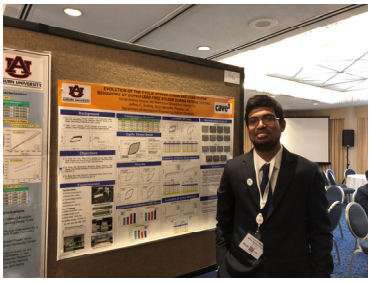
Nakul Kothari



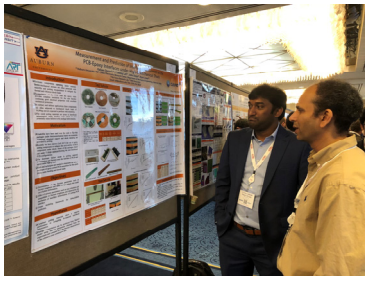
Shantanu Deshpande



Kartik Goyal

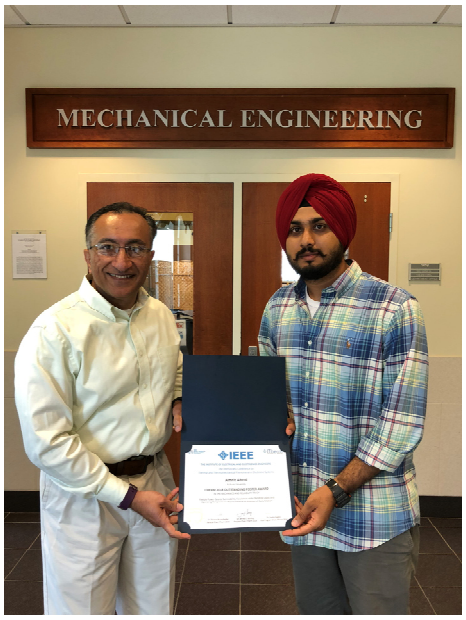


Mohd Aminul Hoque



Kalyan Dornala

CAVE3 Researchers Win Top-Honors at ITHERM 2018 Conference in San Diego, CA.



The following CAVE3 papers from ITHERM 2018 were recognized as best and outstanding papers in the oral-session and poster-session at the conference.

LEFT
Professor Lall with Amrit Abrol

BELOW
Professor Lall (Right) receiving Outstanding Paper Award at ITHERM 2018 from Thomas Brunschwiler, General Chair (left)

Outstanding Paper Award,
Mechanics and Reliability Track, Oral-Session
P. Lall, Y. Luo and L. Nguyen, A Novel Numerical Multiphysics Framework for the Modeling of Cu-Al Wire Bond Corrosion under HAST Conditions, ITHERM, San Diego, CA, US, pp. 1177-1184, May 29-June 1, 2018.

Outstanding Paper Award, Poster-Session
P. Lall, A. Abrol, B. Leever and J. Marsh, Flexible Power-Source Survivability Assurance under Bending Loads and Operating Temperatures Representative of Stresses of Daily Motion, ITHERM, San Diego, CA, US, pp. 1027-1035, May 29-June 1, 2018.

Best Paper Award, Poster-Session
A. Fahim, S. Ahmed, J. Suhling and P. Lall, Mechanical Characterization of Intermetallic Compounds in SAC Solder Joints at Elevated Temperatures, ITHERM, San Diego, CA, US, pp. 1081-1091, May 29-June 1, 2018.

Lall wins IEEE Outstanding Sustained Technical Contributions Award

Professor Lall (Left) receiving the Outstanding Sustained Contributions Award from Avram Bar-Cohen, President of IEEE Electronic Packaging Society at ECTC 2018 in San Diego.

Pradeep Lall, MacFarlane Endowed Professor in department of mechanical engineering, is the 2018 recipient of the IEEE's outstanding Sustained Technical Contributions Award for outstanding sustained contributions to the design, reliability and prognostics for harsh environment electronics systems. The award recognized Lall's seminal contributions to the field of harsh environment electronics. Lall is widely credited with the development of leading indicators of failure for prognostics health management of electronic systems to allow for early identification of faults that may impair system operation. Lall is the author and co-author of over 500 journal and conference papers in the field of electronics reliability, safety, energy efficiency, and survivability.

"This award is recognition of Dr. Lall's international reputation and the impact of his contributions to state-of-the-art innovation," said Christopher B. Roberts, dean of the Samuel Ginn College of Engineering. "His work has positioned Auburn Engineering to be a leader in harsh environment electronics."

"Electronics is pervasive in today's consumer products and many of the functions are safety critical", Lall said. "Take present day automobiles -- electronics enables much of the safety critical circuitry in present-day cars," Lall said. "Examples include lane-departure warning systems, collision avoidance systems and park and drive assist systems. Given the level of criticality and the need for continued reliable operation, it is important that problems be identified much prior to catastrophic failure. Much of the electronics resides under the hood of the automobile where temperatures and vibration loads are very high. Ensuring survivability for sustained operation of electronics is a continuing evolving challenge with the miniaturization of electronics."

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. Lall is a fellow of the IEEE. The award was conferred at the IEEE Electronic Components and Technology Conference (ECTC), a premier international event attended by more than 1,700 attendees in San Diego in May. Lall received $3,000 and a certificate for his achievements. IEEE is the world's largest technical professional organization for the advancement of technology. Lall is also a member of the Technical Council and Governing Council of NextFlex and is director of the NSF Center for Advanced Vehicle and Extreme Environment Electronics at Auburn University. He has previously been recognized by the National Science Foundations-IUCRC's Schwarzkopf Prize for Technology Innovation in 2016. Lall is the recipient of The Alabama Academy of Science Wright A. Gardener Award, the IEEE Exceptional Technical Achievement Award, ASME-EPPD Applied Mechanics Award, SMTA's Member of Technical Distinction Award, Auburn University's Creative Research and Scholarship Award, the Samuel Ginn College of Engineering Senior Faculty Research Award, and 20 best paper awards at national and international conferences.

Where are they now…..

CAVE3 has had a long history of making an impact in workforce development in the field of harsh environment electronics. Students have gone on to have successful careers . I want to highlight two students I met at recent conferences earlier this year.

Rahul Vaidya graduated with a MS degree in Mechanical Engineering from Auburn University in 2010. Rahul's research was on the topic of prognostics health management. Presently, Rahul works for Oculus VR (part of FaceBook) in the role of a reliability engineer. Prior to joining Oculus, Rahul worked for Amazon Lab126 and Cisco Systems. Rahul was a graduate research assistant in CAVE3 and advised by Professor Lall.

Thesis Title: Interrogation of System State of Lead-Free Electronics Subjected to Mixed Sequential Steady-State and Cyclic Thermal Environments (2010).

Chandan Bhat graduated with a MS degree in Mechanical Engineering from Auburn University in 2008. Chandan's research was in the area of prognostics health management. Presently, Chandan is with Xilinx in the role of a Semiconductor Packaging Engineer. Prior to joining Xilinx, Chandan worked for Cree for over 9-years. Chandan was a graduate research assistant in CAVE3 and advised by Professor Lall.

Thesis: Solder Joint Reliability & Prognostication of Lead Free Electronics in Harsh Thermo-Mechanical Environments (2008)

Left-to-Right: Professor Lall (Left) with Rahul Vaidya (Right) at the IRPS Conference in San Francisco, CA, March 13, 2018

Left-to-Right: Chandan Bhat (Left) with Professor Lall (Right) at the ECTC Conference in San Diego, CA, May 31, 2018

Selected Recent Publications

1. P. Lall, H. Zhang and R. Lall, "PHM of state-of-charge for flexible power sources in wearable electronics with EKF," in *Proceedings of IRPS*, Burlingame, CA, US, March 11-15, 2018.
2. P. Lall, K. Mirza and D. Locker, "Prognostics health management of electronic systems — A reliability physics approach," in *Proceedings of IRPS*, Burlingame, CA, US, March 11-15, 2018.
3. Lall, P., & Deshpande, S. (May 29-June 1, 2018). Reliability of Copper, Gold, Silver, and PCC Wirebonds Subjected to Harsh Environment. *Proceedings of ECTC*, (pp. 724-735). San Diego,CA, US.
4. Lall, P., & Thomas, T. (May 29-June 1, 2018). Prognostication of Damage on Automotive Underhood Electronics Subjected to Temperature and Vibration. *Proceedings of ECTC*, (pp. 1330-1342). San Diego,CA, US.
5. Lall, P., Abrol, A., & Marsh, J. (May 29-June 1, 2018). Effect of Shallow Cycling on Flexible Power-Source Survivability Under Bending Loads and Operating Temperatures Representative of Stresses of Daily Motion. *Proceedings of ECTC*, (pp. 2345-2353). San Diego,CA, US.
6. Lall, P., Luo, Y., & Nguyen, L. (May 29-June 1, 2018). Numerical Multiphysics Model for Cu-Al Wire Bond Corrosion Subjected to Highly-Accelerated Stress Test. *Proceedings of ECTC*, (pp. 1622-1633). San Diego,CA, US.
7. Lall, P., Yadav, V., & Suhling, J. (May 29-June 1, 2018). Anand Parameters for Modeling Prolonged Storage on High Strain Rate Mechanical Properties of SAC-Q Leadfree Solder at High Operating Temperature. *Proceedings of ECTC*, (pp. 448-460). San Diego,CA, US.
8. Lall, P., Zhang, H., & Lall, R. (May 29-June 1, 2018). Flexible Wearable Biometric Band and Smartphone Application for Prevention of Sudden Causes of Death. *Proceedings of ECTC*, (pp. 1784-1792). San Diego,CA, US.
9. Ahmed, S., Wu, J., Fu, N., Suhling, J., & Lall, P. (May 29-June 1, 2018). Quantification and Modeling of Microstructural Evolution in Lead Free Solders During Long Term Isothermal Aging. *Proceedings of ECTC*, (pp. 162-172). San Diego,CA, US.
10. Alam, M., Suhling, J., & Lall, P. (May 29-June 1, 2018). High Temperature Mechanical Behavior of SAC and SAC+X Lead Free Solders. *Proceedings of ECTC*, (pp. 1775-1784). San Diego,CA, US.
11. Chowdhury, M. M., Hoque, M. A., Fu, N., Suhling, J., Hamasha, S., Lall, P., & . (May 29-June 1, 2018). Characterization of Material Damage and Microstructural Evolution Occurring in Lead-Free Solders Subjected to Cyclic Loading. *Proceedings of ECTC*, (pp. 865-875). San Diego,CA, US.
12. Fahim, A., Ahmed, S., Suhling, J., & Lall, P. (May 29-June 1, 2018). Nanomechanical Characterization of Intermetallic Compounds in Lead-Free Solder Joints. *Proceedings of ECTC*, (pp. 2353-2353). San Diego,CA, US.
13. Ahmed, S., Suhling, J., & Lall, P. (May 29-June 1, 2018). Evaluation of Aging Induced Microstructural Evolution in Lead Free Solders Using Scanning Probe Microscopy. *Proceedings of ITHERM*, (pp. 1062-1071). San Diego, CA, US.
14. Akkara, F. J., Zhao, C., Alathamneh, R., Su, S., Abueed, M., Hamasha, S., . . . Lall, P. (May 29-June 1, 2018). Effect of Solder Sphere Alloys and Surface Finishes on the Reliability of Lead-free Solder Joints in Accelerated Thermal Cycling. *Proceedings of ITHERM*, (pp. 1374-1380). San Diego, CA, US.
15. Alam, M., Suhling, J., & Lall, P. (May 29-June 1, 2018). A Comparative Study of the High Temperature Mechanical Behavior of Lead Free Solders. *Proceedings of ITHERM*, (pp. 773-777). San Diego, CA, US.
16. Chen, C., Suhling, J., & Lall, P. (May 29-June 1, 2018). Comparison of FEA Modeling Techniques for Plastic Ball Grid Array Assemblies. *Proceedings of ITHERM*, (pp. 1195 -1206). San Diego, CA, US.
17. Chen, C., Suhling, J., & Lall, P. (May 29-June 1, 2018). Improved Submodeling Finite Element Simulation Strategies for BGA Packages Subjected to Thermal Cycling. *Proceedings of ITHERM*, (pp. 1146-1155). San Diego, CA, US.
18. Chen, J., Nguyen, Q., Roberts, J., Suhling, J., Jaeger, R., & Lall, P. (May 29-June 1, 2018). Moisture-induced Die Stresses in PBGA Packages Exposed to Various Environments. *Proceedings of ITHERM*, (pp. 1112-1120). San Diego, CA, US.
19. Chowdhury, M. M., Fu, N., Hoque, M. A., Ahmed, S., Suhling, J., Hamasha, S., & Lall, P. (May 29-June 1, 2018). Effects of Mechanical Cycling on the Microstructure of SAC305 Lead Free Solder. *Proceedings of ITHERM*, (pp. 1324-1334). San Diego, CA, US.
20. Chowdhury, P., Suhling, J., & Lall, P. (May 29-June 1, 2018). Mechanical Characterization of Solder Mask Materials. *Proceedings of ITHERM*, (pp. 1133-1142). San Diego, CA, US.
21. Fahim, A., Ahmed, S., Suhling, J., & Lall, P. (May 29-June 1, 2018). Mechanical Characterization of Intermetallic Compounds in SAC Solder Joints at Elevated Temperatures. *Proceedings of ITHERM*, (pp. 1081-1091). San Diego, CA, US.
22. Hassan, K. R., Suhling, J., & Lall, P. (May 29-June 1, 2018). The Influence of Poisson's Ratio on the Reliability of SAC Lead Free Solder Joints. *Proceedings of ITHERM*, (pp. 1207-1217). San Diego, CA, US.
23. Hoque, M. A., Chowdhury, M. M., Fu, N., Suhling, J., Hamasha, J., Hamasha, S., & Lall, P. (May 29-June 1, 2018). Evolution of the Cyclic Stress-strain and Constitutive Behaviors of Doped Lead Free Solders During Fatigue Testing. *Proceedings of ITHERM*, (pp. 1387-1396). San Diego, CA, US.
24. Lall, P., Abrol, A., Leever, B., & Marsh, J. (May 29-June 1, 2018). Flexible Power-Source Survivability Assurance under Bending Loads and Operating Temperatures Representative of Stresses of Daily Motion. *Proceedings of ITHERM*, (pp. 1027-1035). San Diego, CA, US.
25. Lall, P., Abrol, A., Locker, D., & Hughes, B. (May 29-June 1, 2018). Damage Evolution in MEMS Pressure Sensors during High Temperature Operating Life and Prolonged Storage at Sub-Zero Temperature. *Proceedings of ITHERM*, (pp. 1050-1061). San Diego, CA, US.
26. Lall, P., Deshpande, S., Kothari, N., & Nguyen, L. (May 29-

Selected Recent Publications

June 1, 2018). Effect of Green EMCs on Fatigue Reliability of Molded Cu Wirebond System. *Proceedings of ITHERM*, (pp. 1041-1049). San Diego, CA, US.

27. Lall, P., Deshpande, S., Kothari, N., & Nguyen, L. (May 29-June 1, 2018). Effect of Thermal Cycling on Reliability of QFN Packages. *Proceedings of ITHERM*, (pp. 1357-1367). San Diego, CA, US.
28. Lall, P., Dronala, K., Deep, J., & Lowe, R. (May 29-June 1, 2018). Measurement and Prediction of Interface Crack Growth at the PCB-epoxy Interfaces under High-G Mechanical Shock. *Proceedings of ITHERM*, (pp. 1097-1106). San Diego, CA, US.
29. Lall, P., Goyal, K., Leever, B., & Marsh, J. (May 29-June 1, 2018). Thermo-mechanical Deformation in Flexible-board Assemblies during Reflow and Post-assembly Usage. *Proceedings of ITHERM*, (pp. 26-32). San Diego, CA, US.
30. Lall, P., Kpthari, N., Deep, J., & Lowe, R. (May 29-June 1, 2018). Analysis of Progressive Damage in Fuze Electronics using Micro-computed Tomography and Finite Element Models. *Proceedings of ITHERM*, (pp. 1160-1168). San Diego, CA, US.
31. Lall, P., Luo, Y., & Nguyen, L. (May 29-June 1, 2018). A Novel Numerical Multiphysics Framework for the Modeling of Cu-Al Wire Bond Corrosion under HAST Conditions. *Proceedings of ITHERM*, (pp. 1177-1184). San Diego, CA, US.
32. Lall, P., Narangaparambil, J., Abrol, A., Leever, B., & Marsh, J. (May 29-June 1, 2018). Development of Test Protocols for the Flexible Substrates in Wearable Applications. *Proceedings of ITHERM*, (pp. 1120-1127). San Diego, CA, US.
33. Lall, P., Thomas, T., & Suhling, J. (May 29-June 1, 2018). Feature Extraction and RUL Prediction of SAC Solder Alloy Packages by Different Statistical and Time-frequency Analysis Techniques under Simultaneous Temperature-vibration Loads. *Proceedings of ITHERM*, (pp. 1270-1280). San Diego, CA, US.
34. Lall, P., Yadav, V., Suhling, J., & Locker, D. (May 29-June 1, 2018). Effect of Prolonged Storage on High Strain Rate Mechanical Properties of SAC-Q Leadfree Solder at High Operating Temperature. *Proceedings of ITHERM*, (pp. 1296 -1310). San Diego, CA, US.
35. Lall, P., Yadav, V., Zhang, D., & Suhling, J. (May 29-June 1, 2018). Reliability of SAC Leadfree Solders in Automotive Underhood Temperature-Vibration. *Proceedings of ITHERM*, (pp. 1255-1270). San Diego, CA, US.
36. Lall, P., Zhang, H., & Lall, R. (May 29-June 1, 2018). Novel Flexible Bioelectronics Device and Software Application for Prevention of Sudden Causes of Death. *Proceedings of ITHERM*, (pp. 37-46). San Diego, CA, US.
37. Nguyen, Q., Roberts, J., Suhling, J., Jaeger, R., & Lall, P. (May 29-June 1, 2018). A Study on Die Stresses in Flip Chip Packages Subjected to Various Hygrothermal Exposures. *Proceedings of ITHERM*, (pp. 1339-1350). San Diego, CA, US.
38. Su, S., Akkara, F., Abueed, M., Jia, M., Hamasha, S., Suhling, J., & Lall, P. (May 29-June 1, 2018). Fatigue Properties of Lead-free Doped Solder Joints. *Proceedings of ITHERM*, (pp. 1243-1249). San Siego, CA, US.
39. Wu, J., Suhling, J., & Lall, P. (May 29-June 1, 2018). Investigation of Microstructural Evolution in SAC Solders Exposed to Short-term and Long-term Aging. *Proceedings of ITHERM*, (pp. 1234-1243). San Diego, CA, US.

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

Auburn University
CAVE 3
Samuel Ginn College of Engineering
1418 Wiggins Hall
Auburn, AL 36849

Non-profit Org.
U.S. Postage
PAID
Permit No. 9
Auburn, AL
36849

Mechanical Engineering-CAVE3-3/2018

cave³ News

Fall 2018

cave.auburn.edu

www.auburn.edu

If you have recently changed your address or have colleagues who would be interested in receiving the CAVE³ News, please fill out the following information and either return it to the above address, fax it to 334-844-1898, or email it to *cave@auburn.edu*.

☐ Please add me to the CAVE News mailing list.

☐ Please remove me from the CAVE News mailing list.

☐ My address has changed, please update it.

☐ Please add me to the CAVE email mailing list.

Name: _____ Country: _____

Title: _____ Phone #: _____

Company: _____ Fax #: _____

Address: _____ E-mail: _____

Comments and suggestions: _____

City: _____ State: _____ Zip: _____ _____