AUBURN UNIVERSITY

SAMUEL GINN
COLLEGE OF ENGINEERING

Spring 2021

cave^3 News

NSF-CAVE3 Electronics Research Center
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Mission Statement

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

Message from Director

In spite of the constraints of the new normal conditions in which we operate, I am glad to say that the student teams have shown resilience to meet the demands of the project deadlines and make stellar progress while balancing the needs of remote classroom instruction. You will hear from the students on the exciting new developments made in the research projects reported this review in number of areas encompassing manufacturing, materials, performance and reliability related to harsh environment electronics and additively printed flexible hybrid electronics.

We have had a banner six-months in which we pressed into operation three new additive platforms acquired earlier including inkjet printing, direct-write printing, and lamination of flexible electronics. The new platforms augment the already formidable capabilities at CAVE3 Electronics Research Center. We reported manufacturing research advancements on each of these platforms for the additive manufacturing of multilayer electronic circuits and multilayer antennas for installation on the skin of unmanned airborne vehicles. In addition, we have demonstrated proof of concept manufacturing processes for component mounting on additively printed circuits, characterized their performance and studied their frequency response in collaboration with Boeing under ongoing project PC4.5. In addition, we worked on the development of flexible encapsulation solution for additively fabricated flexible hybrid electronics. The new solutions allow for flexibility of motion expected in wearable electronics while protecting the electronics from moisture and contaminants. The solutions in collaboration with Flex International were used to fabricate flexible encapsulation demonstrators using the flex-Arduino from NextFlex and the AU Biometric Wristband under project call PC4.1. You will have a chance to see some of these advancements as part of the student presentations at the Spring-2021 review.

CAVE3 students presented a number of papers at the ASME INTERPACK conference held in virtual format from October 27-29, 2020. In total, CAVE3 students presented twenty-eight papers spanning a number of tracks. I am also glad to report that two of the CAVE3 students won the Outstanding-Paper-of-Conference Award at the ASME INTERPACK 2020. The winning papers are:

1. Reliability of Flexible Wearable Band With Printed Sensors for Vital Sign Acquisition, Lall, P., H. Jang, C. Hill, and L. Creel, in Proceedings of the ASME International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, Paper IPACK2020-2644, pp. 1-8, October 27-29, 2020.
2. Process-Consistency in Additive Printed Multilayer Substrates With Offset-Vias Using Aerosol Jet Technology, Lall, P., K. Goyal, and S. Miller, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, Paper IPACK2020-2680, pp. 1-11, October 27-29, 2020.

Dr. Ben Leever of AFRL, Dr. Janos Veres of NextFlex and I co-chaired the track on additive-printed flexible electronics at the ASME INTERPACK 2020. The track brought together researchers focusing on a number of challenges and opportunities related to the development and maturation of flexible hybrid electronics in the form of technical papers and presentations. In addition, I chaired a panel on the additive printed electronics. The panel featured presenters from some of the mainstream additive technologies including aerosol-jet, inkjet, direct-write and large-area screen-printing. The panel included experts from each of the manufacturers for the platforms including Bryan Germann from Optomec, Mike Newton from nScrypt, Don Veri from SUSS MicroTec, and Doug Schardt from Komori America. A number of themes were discussed including challenges, opportunities, and past successes related to the development of high volume process scale-up on each of the platforms.

Earlier on October 15, 2020, I had the opportunity to present as a featured speaker at the SMTAI Additive Electronics TechXchange on the topic of process-property interactions for multilayer flexible substrates with z-axis interconnects. The event brought together researchers in the area of additive electronics from a number of organizations including Auburn University, Duke University, Intel Corporation, Lockheed Martin, Northrop Grumman, and NAVSEA Crane.

Pradeep Lall,
MacFarlane Endowed Distinguished Professor and Director

CAVE3 Consortium Spring 2021 Semi-Annual Technical Review Meeting

The CAVE3 Fall Semi-annual Spring-Review 2021 will be a virtual-live meeting owing to COVID-19 related travel concerns. The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE3) will hold its Spring 2021 Technical Review and Project Planning Meeting via MICROSOFT TEAMS on March 2-5, 2021. In order to accommodate the differing time zones of the membership, the review has been spread out over 4-days from 10am-2pm CT each day. In addition, the member caucus will be held at the end of each day. All the member feedback will be done at the end of the review on Friday, March 5th. The meetings will be recorded and made available to the membership for asynchronous viewing. All current members of the Consortium are invited to attend. The following projects will be presented at the meeting:

- Microstructural Evolution in Aging Lead Free Solders
- High Temperature Tensile and Creep Behavior of Lead Free Solders
- Effects of Thermal Cycling on the Material Behavior of Lead Free Solders
- Effect of Thermal Aging on the Interface Fracture Toughness of the Substrate-UF Interface
- High Strain Rate Properties for SAC305 at Cold Operating Temperatures down to -65°C
- Effect of Shock Angle on Solder-joint Reliability of Potted Assemblies Under High-G Shock
- RUL Estimations of SAC305 Solder PCB's under Different Conditions of Temperature and Vibration Loads
- Process Development for Assembly of Surface-Mount Components to Additively Printed Circuits using ECAs
- COTS Attachment via Additively Dispensed Low Temperature Solder, Printed Phase-Array Antenna using Aerosol Jet, and Direct-Write Printing Platform
- Study of Interface Strength of Flexible Encapsulation for FHE Applications
- Effect of Twisting, Dynamic Folding, Flex-to-Install with Varying Fold Orientations and C-rates on Flexible Power Source Capacity
- Low Temperature High Strain-Rate Material Properties for SAC-Q Leadfree Alloys
- Effect of Sustained High-Temperature Operation on Underfill Material Properties
- Evolution of High Strain Rate Mechanical Properties of SAC-R with High Temperature Storage at 50°C with High and Low Operating-Temperatures
- Degradation Mechanisms of Underfills Subjected to High Temperature Long Term Sustained High Temperature Operation from 150-200°C
- Effect of Sintering Process Conditions for Additive Printing of Multi-Layer Circuits using Aerosol-Jet Process with Blind -Vias
- Feature Vector Identification and Prognostics for Asset Monitoring under Varying G-Levels of Drop and Shock Loads
- Process Development for Additive Printing of Copper with Inkjet
- Development Of Process-recipe For Multi-layer Circuitry Printing With Z-axis Interconnects Using Aerosol-jet Nanoparticle Ink
- Thermal Cycling Reliability of Newly-Developed Solder Materials for Automotive and Harsh Applications
- Thermal Cycling of Different SAC Solder Alloys Compared to SnPb
- Drop Shock Performance of Different SAC Solder Alloys Compared to SnPb
- Fatigue Performance of Individual Lead-free Solder Joints
- Electronic Interconnections under Varying Amplitude Cycling
- Effects of Aging on the Cyclic Fatigue Life of Pb-Free Alloys
- Effects of Alloys Composition on the Performance of SAC+Bi Lead Free Solders
- Analysis of Solder Joint Behavior Including Grain Effects
- Convective Cooling of High-Power Electronics
- Thermal Materials Testing

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UPCOMING CONFERENCES WITH CAVE3 PRESENTERS

2021 IEEE 71st Electronic Components and Technology Conference
Virtual Conference, June 1—July 4, 2021

The Electronic Components and Technology Conference (ECTC) is the premier international event that brings together the best in packaging, components and microelectronic systems science, technology and education in an environment of cooperation and technical exchange. ECTC is sponsored by the IEEE Electronics Packaging Society. The following papers will be presented at the conference:

Lall, P. Zhang, Y., Mehta, V., Kasturi, M., Choudhury, P., Wu, H., Suhling, J., Davis, E., Evolution of Viscoelastic Properties and Interface Fracture Toughness under Sustained High Temperature Operation Typical of Automotive Underhood for up to 1-year, 71st ECTC, Jun 1 – July 4, 2021

Hassan, SM, K., Ahsan, M.A., Fahim, A., Suhling, J., Lall, P., Mechanical Property and Microstructure Evolution in SAC and SAC+X Lead Free Solders Exposed to Various Thermal Cycling Profile, 71st ECTC, Jun 1– July 4, 2021

Lall, P., Yadav, V., Mehta, V., Suhling, J., Low Temperature High Strain Rate Constitutive Behavior of Doped and Undoped SnAgCu Solder Alloys after Prolonged Storage at High Temperature, 71st ECTC, Jun 1– July 4, 2021

Hassan, KM. R., Wu., J., Alam, M.S., Suhling, J., Lall, P., Mechanical Behavior and Reliability of SAC+Bi Lead Free Solders with Various Levels of Bismuth, 71st ECTC, Jun 1– July 4, 2021

Lall, P., Soni, V., Miller, S., Life Prediction of Thin-Flexible Batteries under Dynamic Folding and Flex-to-Install, 71st ECTC, Jun 1– July 4, 2021

Haq, M.A., Hoque, M.A., Suhling, J., Lall, P., Effect of Bismuth Content on the Mechanical Cyclic Properties of SAC+Bi Lead Free Solders, 71st ECTC, Jun 1– July 4, 2021

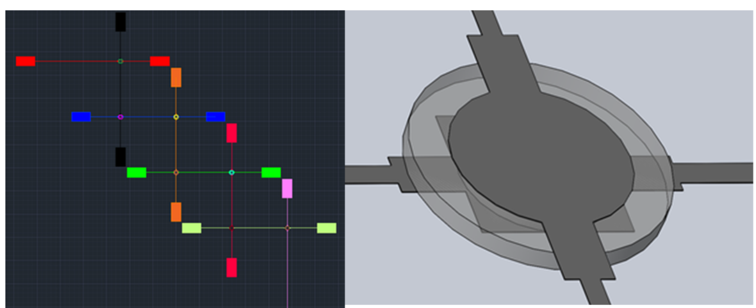
Lall, P., Choudhury, P., Narangaparambil, J., Miller, S., Flexible Encapsulation Process-Property Relationships for Flexible Hybrid Electronics, 71st ECTC, Jun 1– July 4, 2021

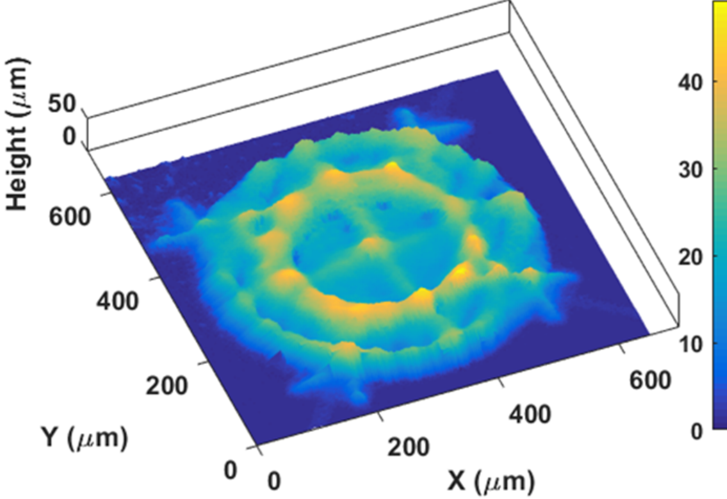
Hoque, M.A., Haq, M.A., Suhling, J., Lall, P., Mechanical Behavior and Microstructure Evolution in Lead Free Solders Subjected to Mechanical Cycling at Elevated Temperatures, 71st ECTC, Jun 1– July 4, 2021

Research Highlights

Z-axis Interconnects in Additive Printed Multilayer Substrates with Offset-Vias Using Aerosol Jet Technology

The transition of additive printed electronics into high volume production requires process consistency to allow quality control of the manufactured product. Process recipes are needed for multilayer substrates with z-axis interconnects in order to enable complex systems. In this project, process recipes have been developed through fundamental studies of the interactions between the process parameters and the mechanical-electrical performance achieved for multilayer substrates. The study reported in this paper focuses on printed vias also known as donut vias. Aerosol jet process parameters studied include carrier mass flow rate, sheath mass flow rate, exhaust mass flow rate, print speed, number of passes, sintering time and temperature, UV-intensity for UV-cure, and standoff height. The electrical performance has been quantified through the measurements of resistance. The mechanical performance has been quantified through measurement of shear load-to-failure. The effect of sequential build-up on the mechanical-electrical properties vs process parameters have been quantified for up-to 8-layers designs. The performance of 5-layer and 8-layer additively printed substrate designs and effect of multiple vias has been compared to assess process consistency.

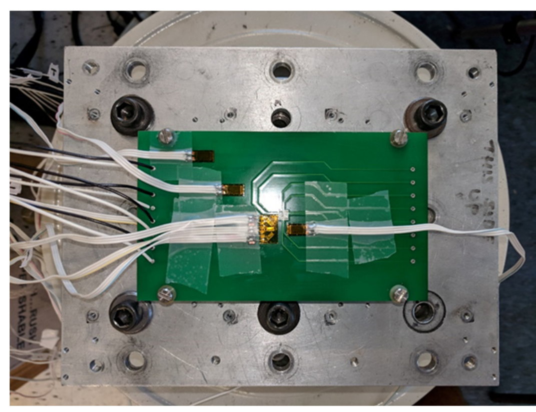




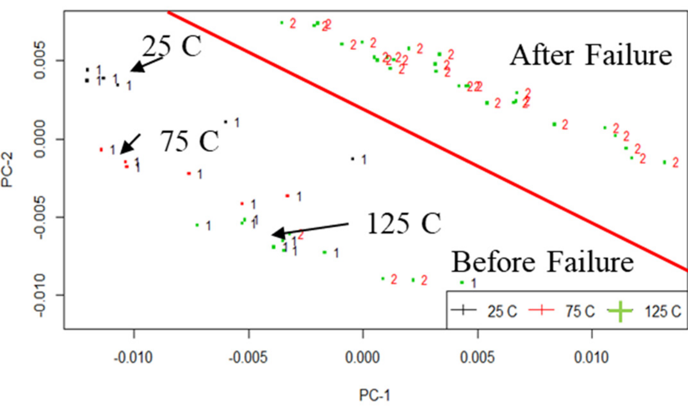
Additively Printed z-axis interconnects via Aerosol Jet

PHM and RUL Estimations under Simultaneous Temperature and Vibration Loads

This study focuses on the feature vector identification of SAC305 solder alloy PCB's of two different configurations during varying conditions of temperature and vibration. The feature vectors are identified from the strain signals, that are acquired from four symmetrical locations of the PCB at regular intervals during vibration. The changes in the vibration characteristics of the PCB are characterized by three different types of experiments. First type of analysis emphasizes the vibration characteristic for varying conditions of acceleration levels keeping the temperature constant during vibration. The second analysis studies the characteristics changes for varying temperature levels by keeping the acceleration levels constant. Finally, the third analysis focuses on the combined changes in temperature and acceleration levels for the board during vibration. The above analyses try to imitate the actual working conditions of an electronic board in an automobile which is subjected to varying environments of temperature and vibration. The strain signals acquired during each of these experiments are compared based on both time and frequency domain characteristics. Different statistical and frequency based techniques were used to identify the variations in the strain signal with changes in the environment and loading conditions. The feature vectors of failure at a constant working condition and load were identified and as an extension to the previous work, the effectiveness of the feature vectors during these varying conditions of temperature and acceleration levels are investigated using the above analyses. The feature vector of a PCB under varying conditions of temperature and load are identified and compared with different operating environments.



High-Temperature Vibration Setup

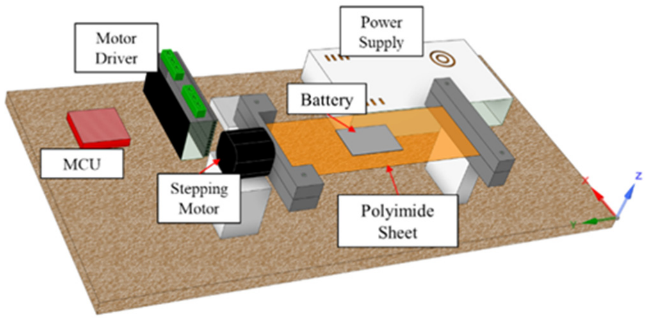


Classification of Before and After Failure Assemblies using PCA Based Feature Vector

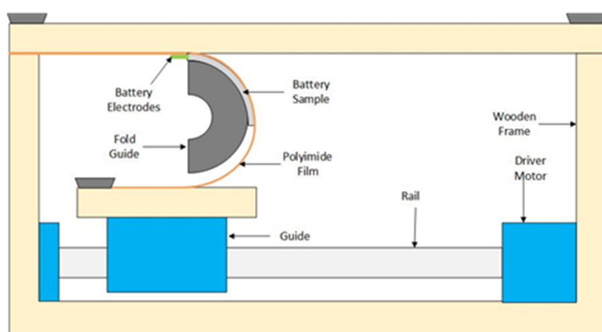
Research Highlights

Twist Reliability of Thin-Flexible Batteries during Charge-Discharge Cycling in Wearable Applications

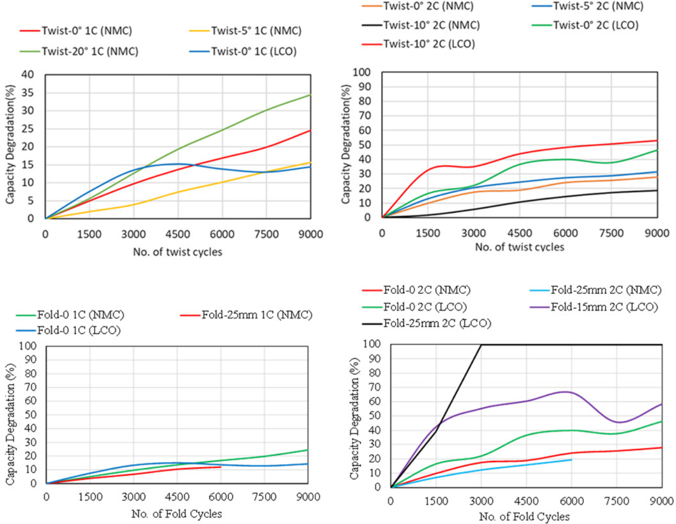
Flexibility of Li-Ion batteries have been recently interesting researchers who study on flexible electronics. The one of major concerns about the flexible Li-Ion battery is reliability of that. Though the flexible battery could be exposed to repeated flexing loads like bend, fold and twist when being used in human body behavior, the research on such that is rare.



Twist Actuation of Thin Flexible Power Sources



Battery Dynamic U-Flexing

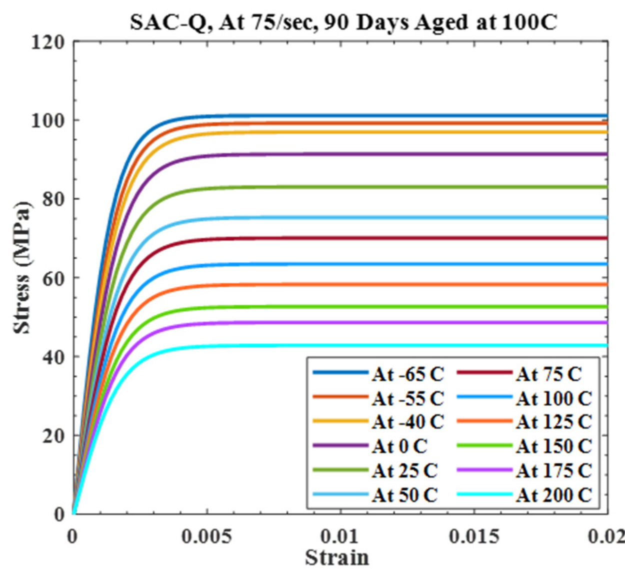


Battery Capacity Degradation versus the number of twist and fold cycles with NMC and LCO batteries

In this study, test protocols for twist and fold reliability of the battery have been developed to replicate stresses of daily motion of human body in a lab-environment. Flexible NMC and LCO batteries have been tested with the twist test-stand. The samples are experiencing the 150 charging-discharging cycles and the 60 twist and fold motion per every discharge cycle. The twist motion and the charging-discharging of the battery have been controlled via micro-controller and the LabView, respectively. Additionally, FEM model have been developed to predict the life of the battery and analyze acceleration factors between test conditions and use conditions.

High Strain Rate Properties of SAC-Q Between –65°C and +200°C After Exposure to Isothermal Aging

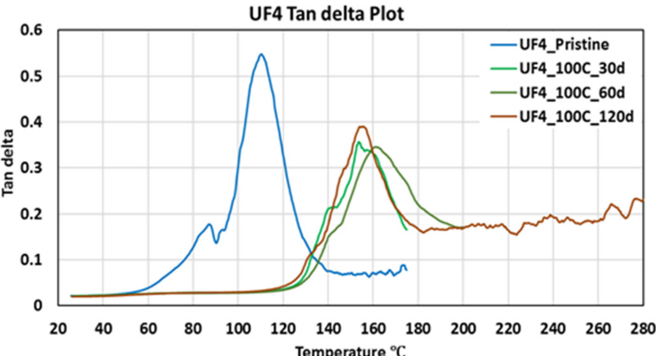
In many industries, such as automotive, oil and gas, aerospace, medical technologies, electronic parts can often be exposed to high strain loads during shocks, vibrations and drop-impact conditions. Such electronic parts can often be subjected to extreme low and high temperatures ranging from -65°C to 200°C. Also, these electronic devices can be subjected to strain rates of 1 to 100 per second in the critical environment. Recently, many doped SAC solder alloys are being introduced in the electronic component including SAC-Q, SAC-R, Innolot. SAC-Q is made with addition of Bi in Sn-Ag-Cu composition. Mechanical characteristic results and data for lead-free solder alloys are extremely important for optimizing electronic package reliability, at high temperature storage and elevated strain rates. Furthermore, the mechanical properties of solder alloys can be changed significantly due to a thermal aging, which is causing modification of microstructure. Data for the SAC-Q solder alloy with a high temp aging and testing at extreme low to high operating temperatures are not available. SAC-Q material was tested °Cto 200°C and at a strain rate up to 75 per second. After the specimens were manufactured and reflowed, specimens were stored at 100°C for the isothermal aging for up to 90 days, before tensile tests were carried out at different operating temperatures. For the wide range of strain rates and test temperatures, stress-strain curves are established. In addition, the measured experimental results and data were fitted to the Anand viscoplasticity model and the Anand constants were calculated by estimating the stress-strain behavior measured in the wide range of operating temperatures and strain rates.



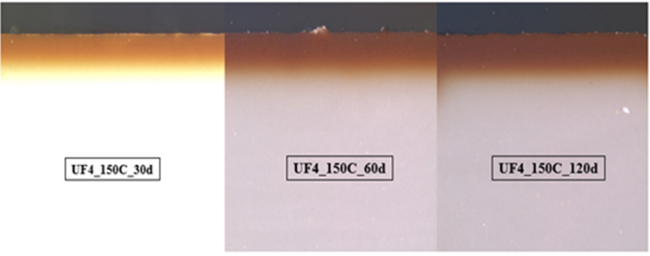
SAC-Q Aged at 100C for 90 days at 75 sec-1

Underfills Subjected to Sustained High Temperature Operation in Automotive Environment

FCBGAs are finding applications in automotive underhood environments where they may be subjected to sustained temperatures of 125-200°C for sustained periods during operation. While, FCGBAs have been previously used in consumer applications where operating temperatures typically range in 55-85°C, relatively little is known on methods to design damage-tolerant packages in automotive underhood environments. In this study, four different types of underfills has been cured and aged. Mechanical tests have been performed on all the four types of underfills to understand the degradation in properties under extended high temperature operation. Uniaxial tensile tests are conducted to study the elastic modulus, ultimate tensile strength and percentage elongation of the underfills. After uniaxial tensile tests, Optical Microscope, SEM and EDS are applied to study the microstructure behaviors of the cross-section area of the underfills. The experimental results are compared before and after aging tests, including pristine, 30 days, 60 days, 90days, 120 days and 240 days. The research focuses on microstructure-property-processing-performance relationships, building the relation between the microstructure evolution and macro-mechanical properties. Reliability physics of high temperature degradation of packaging material is studied.
In this work, the oxidation phenomenon of underfill was studied

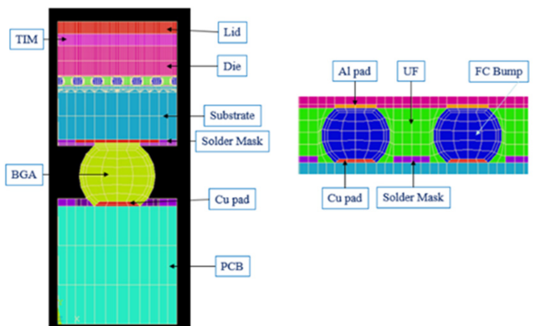


Evolution of tan-δ under Sustained High Temperature

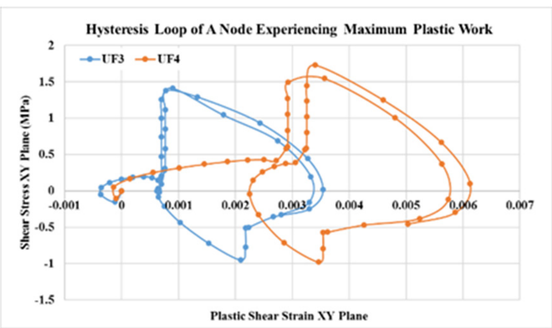


Evolution of Oxidation Layer with Time at 150°C

experimentally by measuring oxidation layer thickness using polarized optical microscope and the dynamic mechanical properties of underfill using DMA (Dynamic Mechanical Analyzer). Two different underfill materials were subjected to three different isothermal exposure which are below, near and above the glass transition temperature of the underfill. The dynamic mechanical viscoelastic properties like storage modulus, loss modulus, tan delta and their respective glass transition temperatures were investigated. Three point bending mode was used in the DMA with an ideal frequency of 1 Hz operating at 3°C/min.



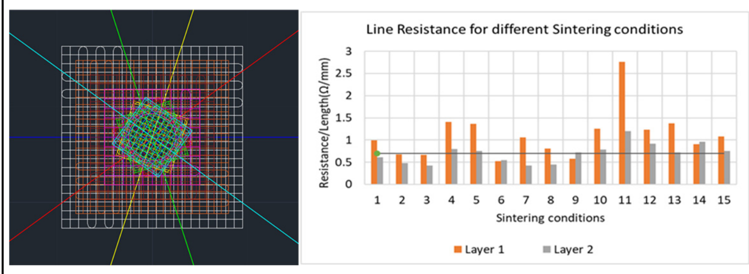
Non-linear FE Model of FCBGA



Hysteresis Loop of Flip-Chip Bump in FCBGA

Effect of Thermal Sintering Conditions in Additively-Printed Multilayer Circuits

In this project, the effect of sintering conditions on the reliability and performance of additively printed multi-layer circuits has been studied. Multi-layer circuits have been designed and fabricated using aerosol-jet printing considering its various effects. The sintering profile has been established for 2-layer, 3-layer and 5-layer circuitry considering the mechanical and electrical properties. The mechanical and electrical properties viz. shear load to failure and resistance respectively changed according to various sintering profiles.



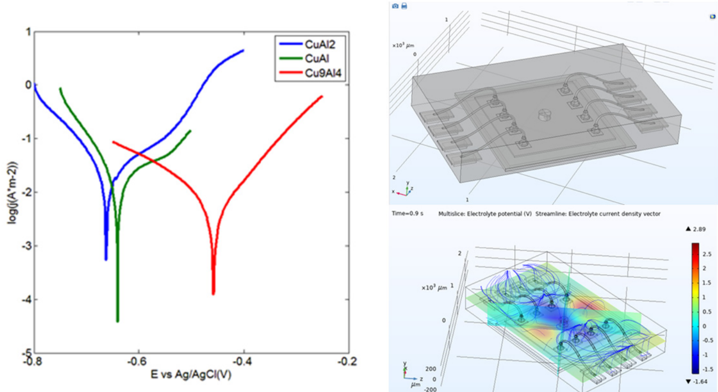
Effect of Sintering Conditions on Electrical Performance

The effect of sintering temperature was as per our previous basic single layer study of the resistance decreases to some extent with an increase in the temperature and decreases with the increasing time. Similarly, the shear load to failure also has a peak value where it is maximum and then due to crack generation the values decreases further along the line. The micro-via printing was easily possible with the polyimide ink and the size of the micro-via was comparable to current industrial standards. There are no dielectric poisoning been seen due to the various effects like platen temperature and various sintering profile. Thus, it can be assumed that there is no

crack generation or voids which may have led to non-functionality of the dielectric layer and micro-vias. The resistance per unit length also does not vary much across multiple layer connections, thus can be considered for various applications like e-skin.

Multiphysics Methods for Reliability Assessment of Cu-Al Wirebonded Interconnects

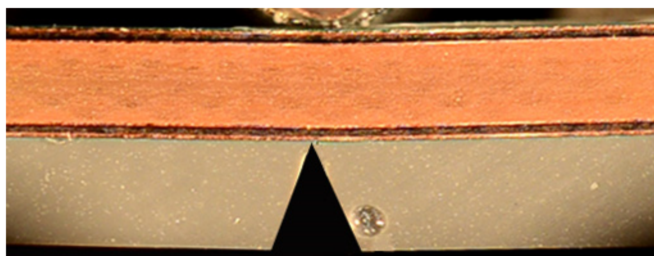
Electronics in automotive underhood environments may be subjected to high temperature in the range of 125-200°C. Transition to electric vehicles has resulted in need for electronics capable of operation under high voltage bias. Automotive electronics has simultaneously transitioned to copper wire-bond from gold wire-bond for first-level interconnections. Copper has a smaller process window and a higher propensity for corrosion in comparison with gold wire bonds. There is scarce information on the reliability of copper wire bonds in presence of high voltage bias under operation at high temperature. In this paper, a multiphysics model for micro galvanic corrosion in the presence of chlorine is introduced. The diffusion cell is used to measure the diffusivity of chlorine in different pH values and different temperatures. Diffusivity measurements are incorporated into the 3D ionic transport model to study the effect of different environmental factors on the transport rate of chlorine. The tafel parameters for copper, aluminum and intermetallics have been extracted through measurements of the polarization curves. The multiple physics of ionic transport in presence of concentration gradient, potential gradient is coupled with the galvanic corrosion.



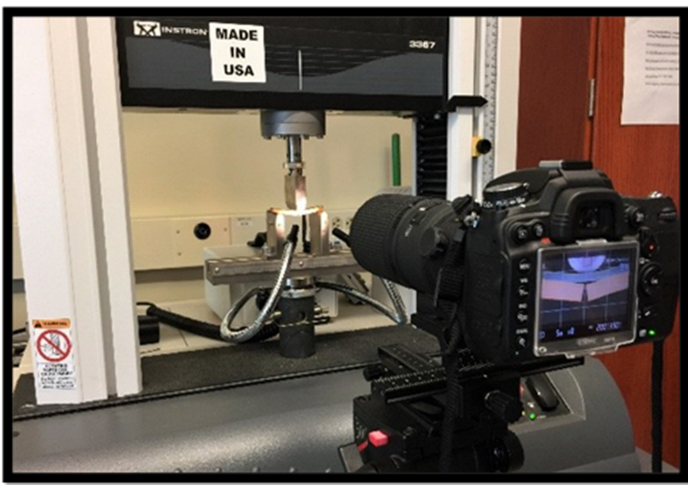
Polarization Curves for Cu-Al IMCs and Multiphysics Models

Effect of Thermal Aging on the Interface Fracture of the PCB-UF Interface

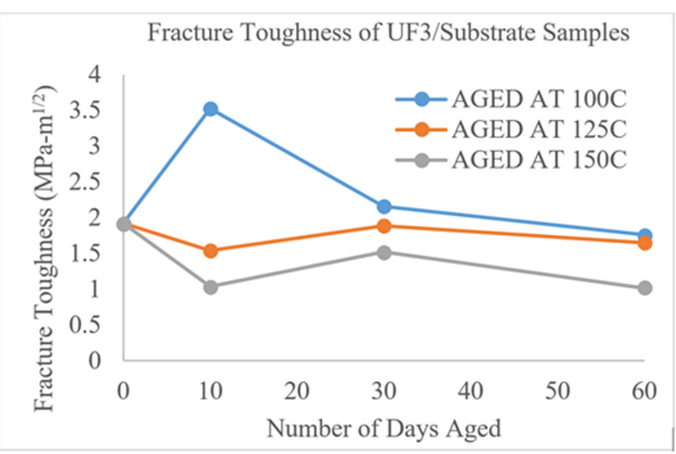
Flip-Chip Ball Grid Arrays (FCBGAs) are finding applications in automotive underhood electronics for enablement of safety-critical functions. Underfills needed to reinforce flip-chip interconnects in FCBGAs need to operate reliably under sustained high temperature operation. Underfill-to-substrate interface is one of the primary failure locations under wide thermal excursions and usually a precursor to flip-chip joint failure. In order to assess the reliability in the end application, there is need for understanding the damage progression of the underfill-to-substrate interface as a function of operating time and operating temperature. In this study, the Substrate-UF interface was exposed to high temperature and the interfacial fracture toughness quantified. A three-point composite beam specimen of PCB/Underfill was fabricated to study the interface and thermally aged for periods of 10 days, 30 days, 60 days at temperatures ranging from 100°C to 150°C. Quasi-static bending was used to observe and determine interfacial delamination of the sample specimen. A 2D-Digital Image Correlation (DIC) method was also employed to understand the Crack tip opening displacement (CTOD), crack initiation and the fracture toughness, CTOD were compared with the aging schedule and temperature.



Bi-material Specimen



Measurement of CTOD



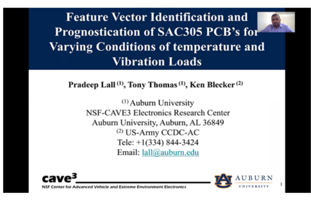
Fracture Toughness vs Time @ High Temperature

The fracture toughness for both materials initially increases but then subsequently drops with the increase in operating time at any operating temperature. The fracture toughness decreases with the increase in operating temperature for any operating time for both underfills UF2 and UF3 studied in this paper. UF2 performs better than UF3 in high temperature aging which could attributed to type of filler material used in both the underfills.

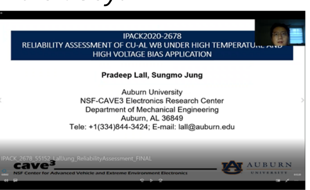
Announcements

CAVE3 Researchers Present Research Papers at the ASME InterPACK 2020 Virtual-Conference

Kartik Goyal

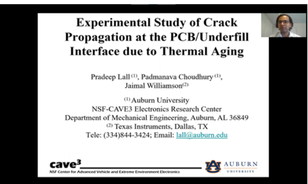


Tony Thomas

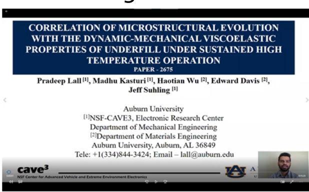


Sungmo Jung

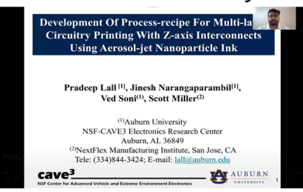
Yunli Zhang



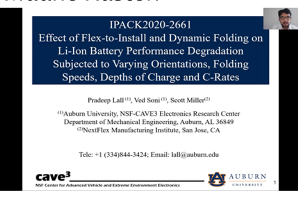
Padmanava Choudhury



Madhu Kasturi

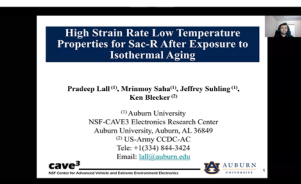


Jinesh Narangaparambil

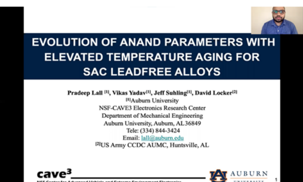


Ved Soni

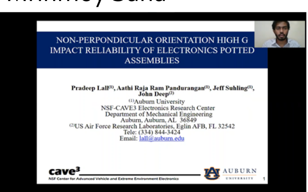
Vishal Mehta



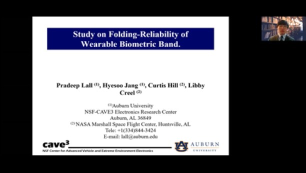
Mrinmoy Saha



Vikas Yadav



Aathi Pandurangan



Hyesoo Jang

CAVE3 students presented papers and posters in virtual format at the ASME INTERPACK 2020 spanning a range of topics from extreme environment electronics, material constitutive behavior, and additively printed electronics.

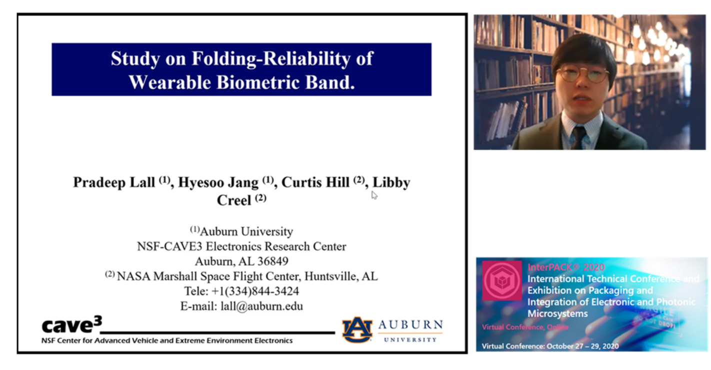
Lall serves as Panelist on Sustainability and Power at the FLEX Conference, Feb 22-26, 2021

Professor Lall served as panelist at the FLEX Conference speaking on a range of subjects related to thin flexible power sources design, performance and reliability in wearable applications. FLEX conference focuses on flexible hybrid, printed electronics products, equipment, processes, and materials, emphasizing the latest technical breakthroughs, unique electronics applications, and business strategies.

CAVE3 Researchers win Top-Honors at the ASME InterPACK 2020 Virtual Conference

Two papers were recognized with the Outstanding-Paper-of-Conference Award at the ASME InterPACK 2020 Conference

1. Reliability of Flexible Wearable Band With Printed Sensors for Vital Sign Acquisition, Lall, P., H. Jang, C. Hill, and L. Creel, in Proceedings of the ASME International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, ASME INTERPACK, Paper IPACK2020-2644, pp. 1-8, October 27-29, 2020.

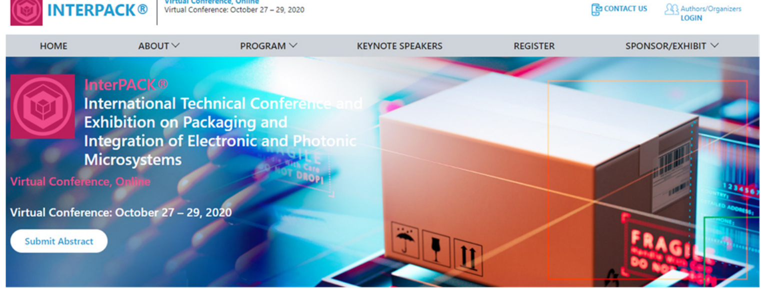


2. Process-Consistency in Additive Printed Multilayer Substrates With Offset-Vias Using Aerosol Jet Technology, Lall, P., K. Goyal, and S. Miller, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, ASME INTERPACK, Paper IPACK2020-2680, pp. 1-11, October 27-29, 2020.

Announcements

Lall Serves as Panelist for Additively Printed Electronics at the ASME INTERPACK 2020

Professor Lall serves as a session chair of a panel on additively printed flexible electronics. The panel featured four of the mainstream technologies including aerosol-jet printing, inkjet printing, direct write, and large-area screen printing. Companies represented including Optomec, nScrypt, SUSS MicroTec, and Komori. The process controls and opportunities were discussed. Professor Lall, Dr. Ben Leever, Dr. Janos Veres served as the track chairs of the Additive Printed Electronic Track at the ASME INTERPACK 2020. The track included a number of session focused on the manufacturing processes, performance and reliability for FHE.

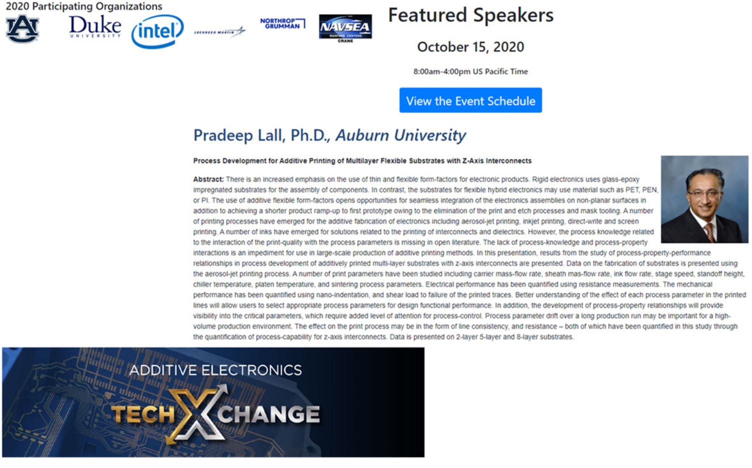


Track-3: Additive Printed Flexible Electronics

Track Co-Chairs: Pradeep Lall, Auburn University
Ben Leever, US Air-Force Research Laboratory
Janos Veres, NextFlex National Manufacturing Institute

Lall Served as Featured Speaker at the SMTA Additive Electronics TechXchange 2020

Professor Lall was a featured speaker at the SMTA Additive Electronics TechXchange on October 15, 2020. His talk focused on process development for additive printing of multilayer substrates.

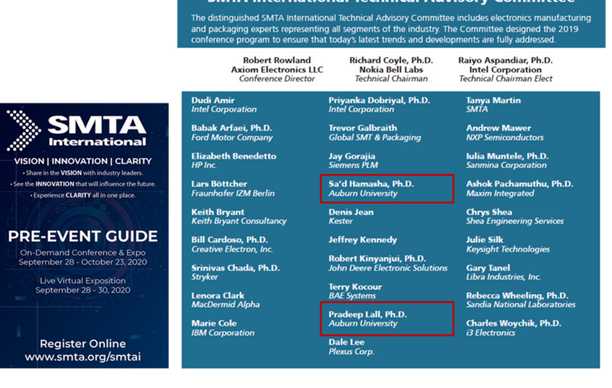


CAVE3 Faculty to Research Lead-Free Defense Electronics as Part of Defense Electronics Consortium

Auburn University will soon help strengthen the economic and force posture of the United States' lead-free defense electronics industrial base through participation in the newly-launched Defense Electronics Consortium (DEC). The interdisciplinary project is a collaboration between faculty in Auburn's industrial and systems engineering and mechanical engineering departments. From the Department of Industrial and Systems Engineering, Dr. Sa'd Hamasha will direct the research program. Participating faculty from the Department of Mechanical Engineering include department chair and Quina Professor Jeffrey Suhling and professor George Flowers, Graduate School dean, as co-principal investigators. According to Hamasha, "The goal is to enable future new solders and electronics packaging technologies and processes for specific defense use cases."

Hamasha and Lall Serve on the SMTA Technical Committee for SMTAI 2020

Professor Hamasha and Professor Lall served on the STMA International Technical Advisory Committee to program the Harsh Environments Track and the Advanced Packaging Technology Track at the SMTAI 2020.



Selected Recent Publications

2020-2021 CAVE3 Papers

1. Lall, P., J. Narangaparambil, B. Leever, and S. Miller, Flexure and Twist Test Reliability Assurance of Flexible Electronics, in Proceedings of the ASME Journal of Electronic Packaging, pp. 031121-1 - 031121-12, Vol. 142 No. 3, September 2020.
2. Lall, P., H. Jang, C. Hill, and L. Creel, Reliability of Flexible Wearable Band With Printed Sensors for Vital Sign Acquisition, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1 -8, October 27-29, 2020.
3. Lall, P., H. Jang, and S. Miller, Twist Reliability Assessment of Flexible Battery in Wearable Applications, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-8, October 27-29, 2020.
4. Lall, P., A. Pandurangan, J. Suhling, and J. Deep, Non-Perpendicular Orientation High-G Impact Reliability of Electronics Potted Assemblies, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-15, October 27-29, 2020.
5. Fahim, A., K. Hasan, J. C. Suhling, and P. Lall, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-9, October 27-29, 2020.
6. Lall, P., V. Yadav, J. Suhling, and D. Locker, Evolution of Anand Parameters With Elevated Temperature Aging for SAC Leadfree Alloys, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-17, October 27-29, 2020.
7. Lall, P., M. Saha, J. Suhling, and K. Becker, High Strain Rate Low Temperature Properties for SAC-R After Exposure to Isothermal Aging, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-11, October 27-29, 2020.
8. Lall, P., V. Mehta, J. Suhling, and K. Blecker, High Strain Rate Mechanical Properties of SAC-Q Between -65 degrees C and +200 degrees C After Exposure to Isothermal Aging, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-13, October 27-29, 2020.
9. Lall, P., V. Soni, and S. Miller, Effect of Flex-to-Install and Dynamic Folding on Li-Ion Battery Performance Degradation Subjected to Varying Orientations, Folding Speeds, Depths of Charge and C-Rates, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-11, October 27-29, 2020.
10. Lall, P., J. Narangaparambil, V. Soni, and S. Miller, Development of Process-Recipes for Multi-Layer Circuitry Printing With Z-Axis Interconnects Using Aerosol-Jet Nanoparticle Ink, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-11, October 27-29, 2020.
11. Lall, P., M. Kasturi, H. Wu, E. Davis, and J. Suhling, Correlation of Microstructural Evolution With the Dynamic-Mechanical Viscoelastic Properties of Underfill Under Sustained High Temperature Operation, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-11, October 27-29, 2020.
12. Lall, P., P. Choudhury, and J. Williamson, Experimental Study of Crack Propagation at the PCB/Underfill Interface due to Thermal Aging, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-7, October 27-29, 2020.
13. Lall, P., Y. Zhang, H. Wu, E. Davis, and J. Suhling, Degradation Mechanisms of Underfills Subjected to Isothermal Long-Term Aging From 150 degrees C to 200 degrees C, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-11, October 27-29, 2020.
14. Lall, P., S. Jung, Reliability Assessment of Cu-Al WB Under High Temperature and High Voltage Bias Application, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-8, October 27-29, 2020.
15. Lall, P., T. Thomas, and K. Blecker, Feature Vector Identification and Prognostics of SAC305 PCB's for Varying Conditions of Temperature and Vibration Loads, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-11, October 27-29, 2020.
16. Lall, P., K. Goyal, and S. Miller, Process-Consistency in Additive Printed Multilayer Substrates With Offset-Vias Using Aerosol Jet Technology, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-11, October 27-29, 2020.
17. M. A. Haq, M.A. Hoque, J.C. Suhling, and P. Lall, Determination of Anand Parameters From Creep Testing of SAC305 Solder Joints, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-7, October 27-29, 2020.
18. Hassan, KM, M.S. Alam, J. Wu, J.C. Suhling, and P. Lall, Time-Lapse Imagery and Quantitative Analysis of Microstructural Evolution of SAC305 BGA Joints During Extreme High Temperature Aging, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-10, October 27-29, 2020.
19. Hoque, M.A., M.A. Haq, J.C. Suhling, and P. Lall, Study of Lead Free Solder Joints Subjected to Isothermal Mechanical Shear Cycling, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-8, October 27-29, 2020.

Selected Recent Publications

20. Hasan, K., M.S. A. Fahim, J.C. Suhling, and P. Lall, Evaluation of the Creep Response of Lead Free Solder Materials Subjected to Thermal Cycling, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-9, October 27-29, 2020.
21. Mondal, D., A. Fahim, KM Hassan, J.C. Suhling, and P. Lall, Deformation Behavior of SAC305 Solder Joints With Multiple Grains, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-9, October 27-29, 2020.
22. Wu, J., M.S. Alam, KM Hassan, J. C. Suhling, and P. Lall, Investigation and Comparison of Aging Effects in SAC305 and Doped SAC+X Solders Exposed to Isothermal Aging, in Proceedings of the ASME 2020 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2020), pp. 1-10, October 27-29, 2020.
23. Lall, P., A. Abrol, N. Kothari, B. Leever, and S. Miller, Process Capability of Aerosol-Jet Additive Processes for Long-Runs Up to 10-Hours, in Proceedings of the ASME Journal of Electronic Packaging, pp. 041003-1 - 041003-12, Vol. 142 No. 4, December 2020.
24. Lall, P., V. Mehta, J. Suhling, and D. Locker, High Strain Rate Mechanical Properties of SAC-Q With Sustained Elevated Temperature Storage at 100 °C, in Proceedings of the ASME Journal of Electronic Packaging, pp. 041104-1 - 041104-12, Vol. 142 No. 4, December 2020.
25. Lall, P., K. Goyal, N. Kothari, B. Leever, and S. Miller, Additively Printed Multilayer Substrate Using Aerosol-Jet Technique, in Proceedings of the ASME Journal of Electronic Packaging, pp. 041110-1 - 041110-11, Vol. 142 No. 4, December 2020.
26. Lall, P., T. Thomas, V. Yadav, J. Narangaparambil, W. Liu, Acceleration Factor Modeling of Flexible Substrates From Actual Human Body Measurements, in Proceedings of the ASME Journal of Electronic Packaging, pp. 041113-1 - 041113-11, Vol. 142 No. 4, December 2020.
27. Lall, P., T. Thomas, Principal Component Analysis and Independent Component Analysis-Based Prognostic Health Monitoring of Electronic Assemblies Subjected to Simultaneous Temperature-Vibration Loads, in Proceedings of the ASME Journal of Electronic Packaging, pp. 011011-1 – 011011-15, Vol. 143 No. 1, March 2021.
28. Lall, P., V. Yadav, J. Suhling, and D. Locker, Evolution of Anand Parameters with Elevated Temperature Aging for SnAgCu Lead-free Alloys, in Proceedings of the ASME Journal of Electronic Packaging, pp. 021005-1 - 021005-17, Vol. 143 No. 2, June 2021.

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