AUBURN UNIVERSITY

SAMUEL GINN COLLEGE OF ENGINEERING

Fall 2019

cave³ 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

We are excited to have NXP join the center membership. NXP is a leading semiconductor supplier for the secure identification, automotive and digital networking industries and we look forward their inputs to the center programs. We have had a very productive summer in which CAVE3 researchers published seminal papers at the national and international conferences in various topical areas including additive printed electronics, flexible electronics, harsh environment electronics reliability, material constitutive behavior, copper wirebonding and flexible batteries. Over 30-students travelled to the ECTC and ITHERM conferences in May-2019. In total, CAVE3 researchers presented over 50-papers at national and international conferences winning top awards for outstanding paper award, best paper award and best overall paper award in the poster session.

Auburn University is a tier-1 academic founding member of the NextFlex Manufacturing Institute. In June-2019, I presented at the FHE applications in Defense Applications Workshop in Arlington, VA. The workshop held at Lockheed Martin Corporation workshop, focused on FHE for Defense Applications, explored opportunities in new and emerging areas that can be improved with the benefits of flexible hybrid electronics – flexible, thin, conformable devices and systems – and future applications now in development. In August-2019, the CAVE3 research team presented at the NextFlex Innovation Day in San Jose, CA. Center developments in the areas of wearable electronics and test-methods were shared at the Innovation Day. I am glad to report that the CAVE3 research teams are kicking off two new projects on the topics of flexible encapsulation and additively printed multilayer antennas. The projects will address the needs in the areas of packaging of flexible electronics in addition to enabling additive technologies for wireless applications. In August, CAVE3 researchers also presented at the SRC Annual Review on a project related to the development of high-temperature automotive packaging. CAVE3 students Madhu Kasturi pursued internship at Texas Instruments and Abdullah Fahim pursued internship at NXP.

A number of key advances in additive printed flexible electronics will be shared at the Fall-Review Meeting. Research teams have made key advances in the development of manufacturing processes for additive printing of flexible electronics. Process-performance relationships have been established relating the manufacturing processes with the electrical and mechanical performance. In addition, data has been gathered on the extended time stability of the print performance for print-runs up to 10-hours quantifying the process capability index for the assessment of the propensity of defects. In addition, the research teams have developed foundational data for operational stresses expected in the applications for flexible and flex-to-install applications. Test protocols have been developed for the assessment of the reliability for assurance of survivability in operation. The test-protocols have been developed to address the key need for test-levels needed for a variety of applications in wearable electronics. Processes for multilayer substrates have been developed for z-axis interconnects. Researchers will present key findings on the printing processes for multi-layer substrates with z-axis interconnects for up to 4-layers.

Flexible electronics requires the flexible power sources, which can operate under stresses of flexing, folding, stretching and twisting. Researchers will present results on the reliability of flexible power sources under flexing applications and various charging rates. The center teams have developed custom-platforms with switch-mode power supplies for charging with a number of charging rates. Using the CAVE3 charging platforms, battery charging and discharging can be done concurrently with the presence of stresses of daily motion – a unique capability required for the assessment of power sources. Key advances will be presented on the topics of copper-aluminum wirebonding, material constitutive behavior. Findings on the effects of sustained exposure to high temperature on the evolution of material constitutive behavior will be presented.

Pradeep Lall
MacFarlane Distinguished Professor and Director

CAVE3 Consortium Fall 2019 Technical Review Meeting

The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE³) will hold its Fall 2019 Technical Review and Project Planning Meeting on September 11-12, 2019 in Auburn University's Wiggins Hall. All current members of the Consortium are invited to attend. The following projects will be presented at the meeting:

- Effect of Drop Angle Variation on Surface Mount Electronics under High G Shock
- Reliability of Additively Printed Traces on a Polymer Substrate Subjected to Mechanical Stretching
- Functional Testing of the NASA-MSFC Flexible Cypress Band
- Effect of Sintering temperature on the Fatigue life of Additively Printed Electronics during Cyclic Bending
- Measurement of Interfacial Fracture Toughness and Cohesive Zone Models of Potting Compounds with FR4 PCBs
- Stress Strain Analysis on Stitch Bond of Cu-Al Wirebonds Using X-ray Micro-CT Technique
- Process Study for Multilayer MicroVias
- Effect of Solder-Joint voiding using X-ray MicroCT data-based FE Models with Experimental Validation
- High Strain Rate Mechanical Properties of SAC-Q with Constant High Temperature Storage at 100°C
- Measurement of Interface Crack Growth at the PCB-Underfill Interfaces under Three-point bend load
- Effect of Shallow Charging On Flexible Lithium ion Battery Capacity Subjected to Differing C-Rates And Various Temperatures
- Failure Modes of Flexible Electronics Under Mechanical Vibration
- Sensitivity of Sensor and Use Conditions on the Detectability of Accrued Damage for PHM under Combined Temperature Vibration
- Reliability of SAC Leadfree Solders in Automotive Underhood Temperature-Vibration
- Effect of Prolonged Storage up to 1-Year on Anand Parameters for SAC105 Leadfree Alloys
- Evolution of Anand Parameters for SAC-Q Solder Alloy After Prolonged Storage up to 1-Year at High Strain Rate at Very High Operating Temperature
- Control-Indicators for High-Temperature Tolerance of Electronics Parts
- 3-D Numerical Multiphysics Model for Cu-Al Wire Bond Corrosion
- Thermal Cycling Reliability of Newly Developed Lead-Free Solders for Harsh Environments
- Experimental Investigation of Geometrically Modified Wicked Heat Pipes
- Effect of Creep and Fatigue on Individual SAC305 Solder Joint Reliability in Iso-thermal Cycling
- Effect of Bi on the Shear Properties of Electronics Interconnection Considering Aging
- Electronic Interconnections under Varying Amplitude Cycling
- Evolution of the Microstructure of Lead Free Solders Subjected to both Aging and Cyclic Loading
- Effect of test temperature and prior aging on the cyclic stress-strain behavior of lead-free solders
- Effect of Aging on the Fatigue Life of SAC305 Solder Joints in Actual Setting Conditions
- Fatigue Behavior of Actual SAC-based Joints at Elevated Temperatures

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SPECIAL EVENTS

SMTA International 2019

Conference: Sept. 22—Sept. 26, 2019, Rosemont, IL

CAVE3 will be heading the Harsh Environment and Advanced Packaging Technologies Tracks at the SMTA International Conference this year. The Harsh Environment 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 annual SMTA International Conference will be held at the Donald E. Stephens Convention Center in Rosemont, Illinois from Sept. 22— Sept. 26, 2019. Dr. Lall is member of the SMTA International Technical Advisory Committee and a track co-chair of the Advanced Packaging Technologies track. Dr. Hamasha is track co-chair of the Harsh Environments Track. The following papers will be presented by CAVE3 researchers at the conference:

- ◊ Thermal Cycling Reliability of Newly Developed Lead-Free Solders for Harsh Environments, Sa'd Hamasha, Ph.D., Auburn University
- ◊ Microstructure and Mechanical Properties of SAC-Bi Solder Alloys with Aging, Sa'd Hamasha, Ph.D., Auburn University
- ◊ X-ray Micro-Computed Tomography Based FE Models to Capture Realistic Manufacturing Variability in Cu-Al Wirebonds and Solder-Joints in QFNs, Pradeep Lall, Ph.D., Auburn University
- ◊ Effect of Cure Conditions on the Interface Properties and Reliability of Potted Electronics in 25,000g Mechanical Shock, Pradeep Lall, Ph.D., Auburn University

ASME InterPACK 2019

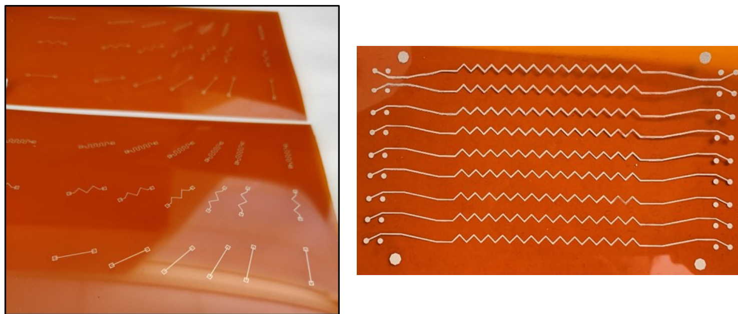
October 7-9, 2019, Anaheim, California

Over thirty-students will travel to the conference to present findings on the topics of additive flexible electronics, design, reliability and material constitutive behavior in extreme environments. The InterPACK Conference is ASME EPPD's flagship conference and has a long history of providing a forum to disseminate and share information on cutting-edge research in the areas of packaging and reliability of electronic devices. The conference will feature over 25-papers from CAVE3 researchers in addition to poster-session and expert-panels.

Research Highlights

Factors Influencing the Line Consistency of Commonly Used Geometries for Additively Printed Electronics

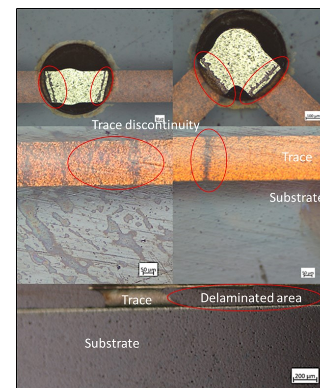
3D printing functional devices onto flexible and conformal substrates is rapidly gaining importance in several industries. The ability to deposit nanoparticles using Aerosol Jet technology provides many of advantages that conventional methods cannot achieve. Aerosol Jet Printing (AJP) technology requires control of the number of process parameters such as sheath flow rate, and carrier gas rate to transport the aerosol mist onto a substrate. There are two ways to obtain the aerosol formation: Ultrasonic Atomizer (UA), which creates the mist by ultrasonic waves and can only be used for inks with viscosity ranging from 1-5cP. The other way utilizes a Pneumatic Atomizer (PA), which smashes the ink on the wall of the jar in order to create the aerosol. PA can be used for a much wider range of ink viscosity, i.e. 1-1000cP. Much work has been demonstrated in the research community regarding the AJP test protocols in refinement of the inks, but if AJP is to be used in large scale production, a print consistency study needs to be performed on the printed lines. The influence of the geometry of silver lines on a flexible substrate has been studied with the aim of creating high quality and conductive lines. In the study, a silver-based ink is utilized to study the line consistency in different geometry of lines printed through a state-of-art Optomec AJ-300printer. Because of the high viscosity of the ink used, PA is used to atomize the ink. Different types of geometry including zig-zag lines, straight lines, and horseshoe pattern are used to study the effect on the conductivity measurements and the physical properties. Process parameters have been optimized by varying the mass flow rate of the ink and the sheath gas flow rate to achieve the highest conductivity of the printed line.



3D Printed Interconnects using (left) Aerosol Jet Process (right) Screen Print

Assessment of Folding Reliability on Wearable Electronics

Reliable technologies against flex-stresses are necessary because a wearable electronic device is susceptible to stresses of daily motion and there is a scarcity of guidance for test-levels needed to assure the reliability of flexible electronics. There is a need for studies focused on the development of accelerated test conditions representative of field applications and the identification of failure mechanisms for test levels. Because of this, CAVE3 has developed various types of test devices with stretching, bending, twisting and folding motion and conducted reliability tests with assorted flexible samples. Most importantly, this study has introduced the test protocol for assessment of the folding reliability. The folding test-stand is capable of replicating the stresses of daily motion in a lab-environment. Experimental analysis on fatigue life of the three types of PCBs, which include subtractive PCB, additive aerosol jet printed flake ink PCB and additive aerosol jet printed nanoparticle in PCB, in cyclical folding load over millions of cycles has been implemented by the developed test device. The test has been conducted in several conditions: PCB type, folding direction, moving distance, folding diameter, strain rate and trace pattern, and it has been found that the various conditions could affect the fatigue life of the PCB. Additionally, a life prediction model has been developed, which shows that fatigue life is affected by strain. The result could imply that the various conditions applied on the folding test are relevant to the strain of test vehicles. For better understanding of the failure mechanism, analysis of failure modes has been performed. The position of failure area is analogous to the expected position, which is the location where it is repeatedly folded and unfolded during the experiments.

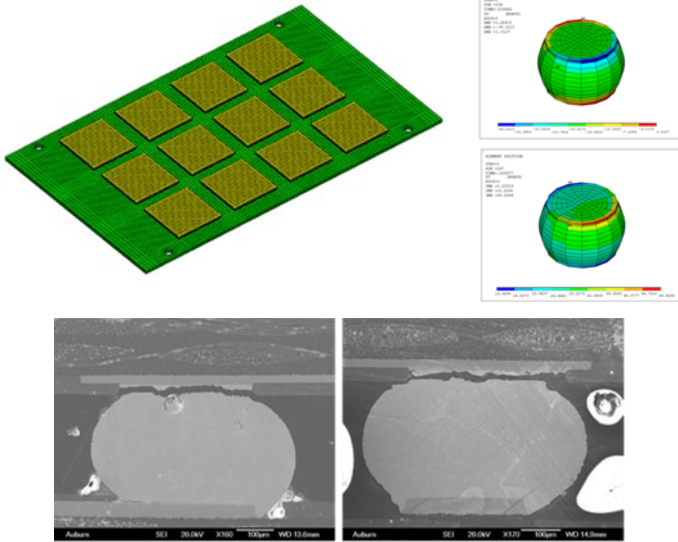


Failure Modes

Reliability of Lead-free Solders in High Temperature Vibration in Automotive Environments

Applications such as in down hole drilling & gas industry, automotive industry and avionics industry are emerging for high temperature electronics combined with vibration loads. Electronic components in an automotive under hood application can be located at the engine and transmission, and can subjected to combined mechanical vibrations and thermal loads. The combined effect of elevated temperature and vibration can cause quicker failure in electronics components. Most of the previous research of solder joints is focused on either single stress of vibration or thermal cycling. Very few researchers have studied the solder joint reliability under simultaneously high temperature and vibration. A CAVE3 study presented reliability for SAC105 and SAC305 alloy compositions at elevated test temperature and vibration. Pristine and aged test board with lead-free SAC daisy chain CABGA packages have been subjected to harmonic vibration at their 1st natural frequency at three test temperatures (25°C, 55°C and 155°C) and vibration with amplitude of 5g, 10g and 14g. A high speed camera was also used to capture the vibration during testing. The experimental system characteristics, such as mode shapes, natural frequencies and displacement amplitudes, for each test condition were compared with global-local FE models. Stresses in solder interconnects have been extracted from sub-model of packages. Hysteresis loop and plastic work density of critical solder joint extracted using FEA based global and local method. S-N curves were obtained for the test vehicle. Failure mode

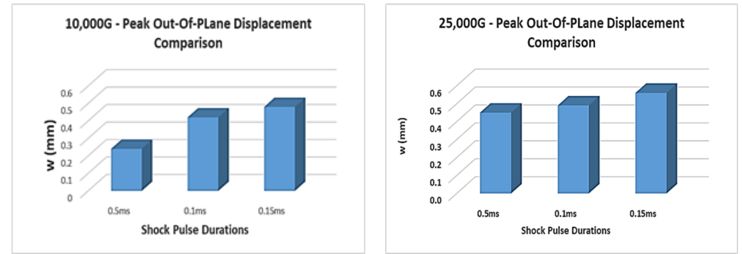
analysis has been done for the test board. Anand Viscoplasticity material data from prior studies have been used to capture the high-strain rate temperature dependent aging behavior of the solder joints. A comparison between simulation and experimental results has been conducted.



Test Vehicle with 12 CABGA Packages; Corner SJs; Failed SJs

Effect of Shock Pulse Variation on Surface Mount Electronics under High G Shock

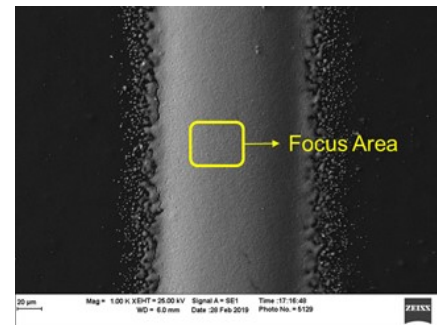
Aerospace and Defense systems differ from their consumer electronics counterparts in their expected lifetimes and reliability. Very high rates of survivability are expected from consumer electronics due to their increased usage in missile and aerospace applications. As with these special applications, the electronics are often subjected to high g forces up to 25,000g. The effect of shock on the electronics can vary directly depending on the duration of the shock pulse. Being one of the significant factors in determining the reliability of electronics under high G forces, the effect of shock pulse variation has not been studied yet. All the test assemblies in our study were restrained with potting, which are studied under the variation in shock pulse. In this study, the effect of varying shock pulses has been taken into account, while the prior works on High G forces have not included it. In addition to the packages, high voltage, C0G dielectric, multilayer ceramic 3640 capacitors are mounted on the circular board and tested passively under High G conditions along with the packages for survivability. With respect to the end application in Defense and Aerospace systems, a circular test board of outside diameter of 110mm and inside diameter of 36mm has been used. Two configurations of the test board have been studied as non-potted and potted assemblies. High Voltage, multilayer ceramic 3640 capacitors were mounted on the SMD side of the test vehicles along with the packages to study reliability under High G shocks. A dual mass shock amplifier was used to amplify the Shock to High G levels. Both the test vehicle configurations were tested under High G force test conditions of 10,000g for 0.05ms, 0.1ms, 0.15ms & 25,000g for 0.05ms, 0.1ms, 0.15ms. The strain and displacement were measured using imaging through high speed cameras and 3-Dimensional image correlation techniques. Both out of plane displacement and full field displacement strains across package and capacitor corners have been studied.

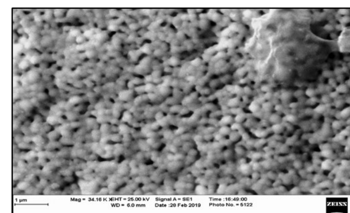


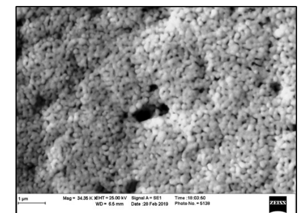
Peak Out-of-Plane Displacement (left) @10,000G (right) @25,000G

Effect of Sintering Temperature on the Fatigue life of Additively Printed Electronics during Cyclic Bending

Flexible devices recently have been emerging in the electronics industry. One of the biggest challenges of Aerosol Jet Printing (AJP) is reducing the resistance of the printed line and getting close to comparison with existing Cu trace resistivity. According to our study, with an increase in sintering temperature at constant sintering time, the resistance and shear strength decrease. There is a need to investigate the effect of varying sintering temperature at a constant time on number of cycles to failure (i.e. fatigue life) during cyclic bending. The current challenge in AJP technology is reducing the resistance of the printed lines. In this study, the failure of the interconnects has been considered according to the end application. Bending (V-bend) motion was considered as the end application to be used in the wearable technologies. The sintering temperature was varied in order to optimize resistance and shear strength. In the previous study, the sintering temperature had not been considered as a parameter to the end application. In this study, the Aerosol jet printing method was used to print the lines using silver nanoparticle ink. The printing was done on a polyimide substrate. The printed sample was then sintered at a different temperature and connectivity was checked for its number of cycles to failure in the v-bend in cyclic loading condition. The reliability of the traces was studied using the ANOVA analysis. The comparison was done using the varying sintered temperature with respect to its application of bending, which resulted in the observation that the point where it can be printed contains lower resistance and higher shear load to failure.



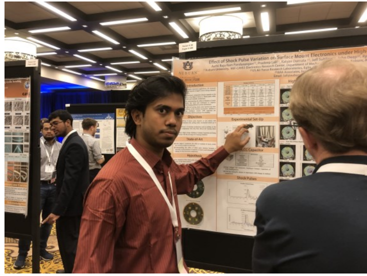




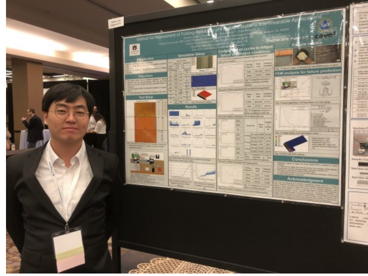
(top) Aerosol Jet Printed Trace (bottom) Sintering Effect @ 120°C; 300°C

Students from Auburn University attend 2019 ITherm and ECTC Conferences in Las Vegas, NV

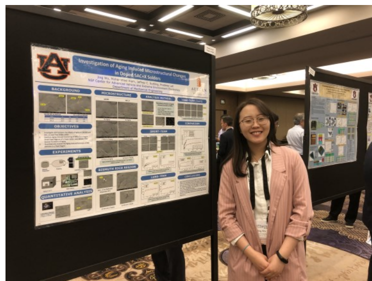
CAVE3 students attended and presented at the 2019 ITherm and ECTC conferences in Las Vegas, NV from May 28-May 31, 2019, and won prestigious awards for their papers and presentations. More than 50 papers were presented by CAVE3 Researchers. Presentations included both oral and poster sessions. A list is included on pages 8-9 of the newsletter.



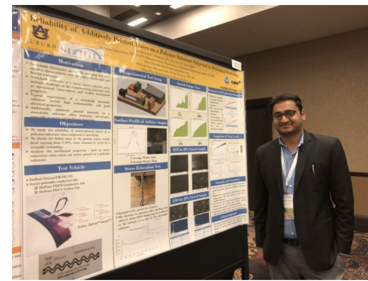
Aathi Pandurangan



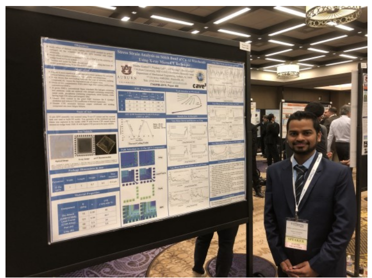
Hyesoo Jang



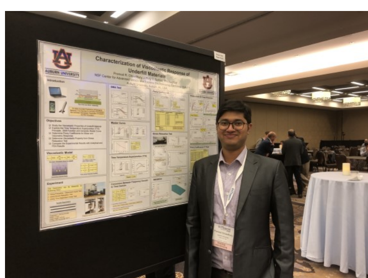
Jing Wu



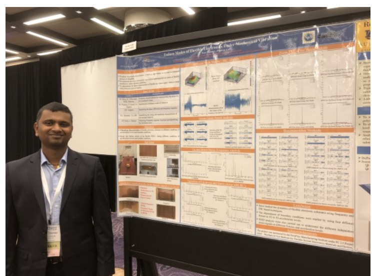
Kartik Goyal



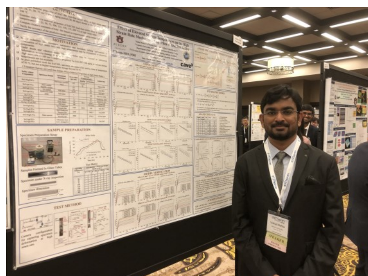
Madhu Kasturi



Promod Chowdhury



Tony Thomas



Vishal Mehta

CAVE3 Students Win Best-Paper Awards at 2019 ITHERM Conference

The following CAVE3 papers from ITHERM 2019 were recognized as 'outstanding' and 'best' at the conference.

◊ Outstanding Paper Award: V. Soni, Lall, P., A. Abrol, B. Leever, and S. Miller, Effect of Shallow Charging on Flexible Power Source Capacity Subjected to Varying Charge Protocols and C-Rates, in Proceedings of the IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, Las Vegas, NV, pp. 198-203, May 28-31, 2019.

◊ Best Paper Award: Wu, J., S. Ahmed, J. Suhling, and P. Lall, Investigation of Aging Induced Microstructural Changes in Doped SAC+X Solders, in Proceedings of the IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, Las Vegas, NV, pp. 405-415, May 28-31, 2019.

◊ Best Overall Paper Award: Su, S., J. Minghong, X. Wei, F. Akkara, S. Hamasha, J. Suhling, and P. Lall, Effect of Surface Finish on the Fatigue Behavior of Bi-based Solder Joints, in Proceedings of the IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, Las Vegas, NV, pp. 1155-1159, May 28-31, 2019.

Dr. Pradeep Lall (right) served as Track Co-chair at ITHERM2019 being recognized by Dr. Jeffrey Suhling (right)

Dr. Lall with CAVE3 Students at ITHERM 2019

Announcements

CAVE3 Represented at NextFlex Innovation Day 2019 in San Jose, CA

The CAVE3 display at NextFlex Innovation Day 2019

Dr. Lall and Mechanical Engineering Ph.D. student, Kartik Goyal, attended the NextFlex Innovation Day in San Jose, California from August 7-8, 2019. Innovation Day provides NextFlex members with the opportunity to network, learn about new technology, and meet prominent individuals in the FHE manufacturing supply chain. It is also an opportunity for government agency partners and dignitaries to learn about NextFlex capabilities as well as a chance for federal and local legislators to be positively influenced by new FHE technology that is improving people's everyday lives.

Dr. Lall (right) explaining recent technological developments and devices produced through CAVE3 research

U.S. Army Redstone Test Center Visits CAVE3 Center to View Additive Printed Electronics Research

Dr. Lall (center-left) presents additive printed electronics research to Redstone Test Center about current CAVE3 projects

Dr. Lall and CAVE3 students welcomed delegation from the U.S. Army Redstone Testing Center to the CAVE3 Lab during the spring 2019 semester. Center research on additive printed flexible electronics, fuzing-testing technologies, high-g testing, harsh environment electronics was presented. The U.S. Army Redstone Test Center's mission is to provide technical expertise and state-of-the-art facilities and capabilities to plan, conduct, analyze, and report the results of test on Missile, Aviation, and Sensor Systems, Subsystems and Components.

CCDC Aviation and Missile Center Employees Express Interest in CAVE3

Dr. Amy Lawrence from CCDC Aviation and Missile Center (CCDC-AvMC) visited the CAVE3 Lab during the Spring 2019 to view center research on additive printed electronics. Printed sensors and development of multilayer flexible circuits was presented.

Dr. Lawrence (Left) discussing additive printed electronics with Dr. Lall (Center) and Nakul Kothari and Ved Soni (Right)

Selected Recent Publications

1. Lall, P., Thomas, T., "Sensitivity of Sensor Location and Use Conditions on the Detectability of Accrued Damage for PHM under Combined Temperature Vibration", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 923-932, Las Vegas, NV, May 28-May 31, 2019.
2. Chowdhury, P.R., Suhling, J.C., and Lall, P., "Characterization of Viscoelastic Reponse of Underfill Materials", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 1321-1331, Las Vegas, NV, May 28-May 31, 2019.
3. Su, S., Akkara, F.J., Raj, A., Zhao, C., Gordon, S., Sridhar, S., Thirugnanasambandam, S., Hamasha, S., Suhling, J., and Evans, J., "Reliability of Micro-Alloyed SnAgCu Based Solder Interconnections for Various Harsh Applications", 2019 IEEE 69th Electronic Components and Technology Conference., pp. 2309-2317, Las Vegas, NV, May 28-May 31, 2019.
4. Lall, P., Thomas, T., Suhling, J., and Blecker, K., "Prognostication of Accrued Damage and Impending Failure Under Temperature-Vibration in Leadfree Electronics", 2019 IEEE 69th Electronic Components and Technology Conference., pp. 505-514, Las Vegas, NV, May 28-May 31, 2019.
5. Su, S., Hoque, M.A., Chowdhury, M.M., Hamasha, S., Suhling, J.C., Evans, J.L., and Lall, P., "Mechanical Properties and Microstructural Fatigue Damage Evolution in Cyclically Loaded Lead-Free Solder Joints", 2019 IEEE 69th Electronic Components and Technology Conference., pp. 792-799, Las Vegas, NV, May 28-May 31, 2019.
6. Wu, J., Suhling, J.C., and Lall, P., "Microstructural Evolution in SAC+X Solders Subjected to Aging", 2019 IEEE 69th Electronic Components and Technology Conference., pp. 1087-1088, Las Vegas, NV, May 28-May 31, 2019.
7. Fahim, A., Hasan, K., Ahmed, S., Suhling, J.C., and Lall, P., "Mechanical Behavior Evolution of SAC305 Lead Free Solder Joints under Thermal Cycling", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 734-744, Las Vegas, NV, May 28-May 31, 2019.
8. Wu, J., Ahmed, S., Suhling, J.C., and Lall, P., "Investigation of Aging Induced Microstructural Changes in Doped SAC+X Solders", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 405-415, Las Vegas, NV, May 28-May 31, 2019.
9. Alam, M.S., Hassan, KM, Suhling, J.C., and Lall, P., "Mechanical Characterization of Microstructural Evolution of SAC and SAC+X Lead Free Solders Subjected to High Temperature Aging", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 319-328, Las Vegas, NV, May 28-May 31, 2019.
10. Hoque, M.A., Chowdhury, M.M., Hamasha, S., Suhling, J.C., and Lall, P., "Evolution of the Mechanical Properties of Lead Free Solder Joints Subjected to Mechanical Cycling", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 295-302, Las Vegas, NV, May 28-May 31, 2019.
11. Su, S., Jian, M., Wei, X., Akkara, F.J., Hamasha, S., Suhling, J., and Lall, P., "Effect of Surface Finish on the Fatigue Behavior of Bi-based Solder Joints", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 1155-1159, Las Vegas, NV, May 28-May 31, 2019.
12. Lall, P., Yadav, V., Suhling, J., and Locker, D., "Effect of Prolonged Storage up to 1-year on Anand Parameters for SAC105 Leadfree Alloys", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 303-318, Las Vegas, NV, May 28-May 31, 2019.
13. Lall, P., Kothari, N., Abrol, A., Suhling, J., Ahmed, S., Leever, B., and Miller, S., "Effect of Process Parameters on the Long-Run Print Consistency and Material Properties of Additively Printed Electronics", 2019 IEEE 69th Electronic Components and Technology Conference., pp. 1347-1358, Las Vegas, NV, May 28-May 31, 2019.
14. Lall, P., Abrol, A., and Kothari, N., "Effect of Print Parameters on Print Consistency of Aerosol Jet Printed Electronics", 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems., pp. 633-642, Las Vegas, NV, May 28-May 31, 2019.
15. Lall, P., Soni, V., Abrol, A., Leever, B., Miller, S., "Effect of Charging Cycle Elevated Temperature Storage and Thermal Cycling on Thin Flexible Batteries in Wearable Applications", 2019 IEEE 69th Electronic Components and Technology Conference., pp. 370-381, Las Vegas, NV, May 28-May 31, 2019.
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