AUBURN UNIVERSITY

SAMUEL GINN
COLLEGE OF ENGINEERING

Spring 2020

cave³ News

NSF-CAVE3 Electronics Research Center

cave.auburn.edu; PH: (334) 844-3424

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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 have had an eventful start to the year with a number of new exciting projects starting at the center. Two of the activity focus-areas are additively-printed electronics for flexible hybrid electronics applications and harsh-environment electronics. In January, we kicked-off a number of projects in both additively printed flexible electronics and harsh environment electronics.

In flexible electronics, one project will examine in detail the issues around the development of manufacturing solutions for providing flexibility in addition to environment protection for flexible hybrid electronics. Flexible electronics may need to be attached to other devices once molded. The needs of flexible electronics are unique as end use may involve flexure, folding, twisting or the application of flexure during the process of installation to place the flexible device.

In a separate project, CAVE3 is working on the development of accelerated test methods for power sources and charging solutions intended for use in flexible hybrid electronics. Power sources in flexible applications may be subject to lamination, encapsulation processes and manufacturing loads as part of the integration into the product. The project examines the issues around the flexing, folding and flex-to-install around mainstream and emerging power sources during integration into products or during operational use environments. Auburn University is teamed with Boeing, Flex, ITN and other notables to develop solutions for power sources in FHE.

In another project, CAVE3 is working with Boeing on the development of high-layer count FHE processing with IC interface demonstration. The project will examine the issues with additively printed multilayer circuits with embedded passives, surface-mounted components, interconnects, integrated circuits using inks, paste, printed dielectrics and solders. The suitability of the manufactured architectures for use in –40 to +85°C is being studied.

CAVE3 has kicked-off new automotive-electronics projects which will lay-down the framework for future automotive safety, navigation and control systems for underhood operation. Electronics in automotive applications has migrated underhood where a number of electronics components and systems may be mounted on engine and on-transmission. Many of the electronic systems provide safety critical functionality. In one of the projects, CAVE3 is working on a project on the development of packaging for sustained operation at 200°C. The new generation of packaging technologies will allow for reliable operation at high temperatures without the use of extensive cooling technologies to meet reliability goals. Further, the emergence of FEVs has resulted in increase emphasis on high-voltage electronics. In a new project, CAVE3 is working on the development of first-level interconnects for high-voltage applications on the automotive platform with capability of sustained operation till 600V under thermal excursions.

Dr. Sa'd Hamasha, the CAVE3 area-leader for leadfree electronics in CAVE3 won the 2019 IPC Michael V. Carano Teacher Excellence Award. This award is the most prestigious award that IPC gives to recognize educators and instructors who enrich the lives of students interested in a career path in the electronics industry. There is only one awardee per year. CAVE3 researchers also won top-honors at the ASME INTERPACK 2019 conference held October 7-9, 2019 in Anaheim, CA. The following paper won the Best-of-Conference Paper Award at the ASME INTERPACK 2019: "Outstanding Paper Award of Conference: Lall, P., Narangaparambil, J., Leever, B., Miller, S., Flexure and Twist Test Reliability Assurance Of Flexible Electronics, ASME InterPACK, IPACK2019-6579, Anaheim, CA, Oct 7-9, 2019. In addition, CAVE3 researchers won the Best-of-Conference Paper Award at the Pan-Pacific Conference 2020. The following paper won the Best-of-Conference Award: Lall, P., Yadav, V., Locker, D., Sustained High-Temperature Vibration Reliability of Thermally Aged Leadfree Assemblies in Automotive Environments, Pan-Pacific Conference, Big Island, HI, pp. 1-17, February 10-13, 2020.

We have also had a strong showing in facilities expansion to add to the already strong capabilities in the fabrication of additively-printed flexible electronics. The CAVE3 Center has added the nScrypt 4-head Electronics Printer to the printing platforms. In addition, CAVE3 has also acquired the Xenon Phot-Sintering System for roll-to-roll sintering of flexible printed substrates. Both new additions will reside in Woltosz Engineering Research Laboratories.

Pradeep Lall,
MacFarlane Distinguished Professor and Director

CAVE^3 Review and Other Conference Events

CAVE3 Consortium Spring 2020 Technical Review Meeting

The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE3) will hold its Spring 2020 Technical Review and Project Planning Meeting on March 4-5, 2020 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 Temperatures
- Failure Modes of Flexible Electronics Under Vibration
- Sensitivity of Sensor and Use Conditions on the Detectability of Accrued Damage for PHM under 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 Electronics Parts
- 3-D Numerical Multiphysics Model for Cu-Al WB 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 SAC-based Joints at Elevated Temperatures
- Effect of Process-Parameters on AJ-Printing of Multi-Layer Circuitry
- Flexible Electronics Under Stresses of Daily Motion
- Investigation and Comparison of Aging Induced Microstructural Changes in SAC305and SAC_Q Lead Free Solders
- Evolution of the Microstructure of Lead Free Solders Subjected to both Aging and Mechanical Loading
- Modeling of Underfilled BGA Assemblies Using Viscoelastic and Elastic Properties
- Characterization of Viscoelastic Response of Underfill Materials
- Mechanical Behavior of SAC305 Lead Free Solder Joints under Thermal Cycling Using Nanoindentation
- Evolution of the Mechanical Behavior of Lead Free Solders Exposed to Thermal Cycling
- Experimental Characterization of the Dependence of Poisson's Ratio of Lead Free Solder on Temperature, Strain Rate, Solidification Profile, and Isothermal Aging
- Evolution of the Cyclic Stress-Strain and Constitutive Behaviors of SAC and SAC+X Alloys and Joints during Fatigue Testing
- Effect of Thermal Aging on the Interface Toughness of the PCB-UF Interface

Contact Information:
1418 Wiggins Hall, Auburn University, Tele: (334) 844-3424

CONFERENCES WITH CAVE3 PRESENTERS

25th Annual SMTA Pan-Pacific Microelectronics Symposium

Conference: February 10-13, 2020, Big Island, HI

Dr. Lall presented papers on two topics of high-temperature vibration and . The Symposium promotes international technical interchange and provides a premier forum for networking among microelectronics professionals and business leaders throughout the world. Paper topics included:

- Lall, P., Yadav, V., Locker, D., Sustained High-Temperature Vibration Reliability of Thermally Aged Lead-Free Assemblies in Automotive Environments, Pan-Pacific Conference, Big Island, HI, pp. 1-17, Feb 10-13, 2020
- Lall, P., Kothari, N., Goyal, K., Miller, S., Extended-Time Process Consistency and Process-Property Relationships for Flexible Additive-Printed Electronics, Pan-Pacific Conference, Big Island, HI, pp. 1-17, Feb 10-13, 2020

FLEX Conference 2020

Conference: February 24-27, 2020, San Jose, CA

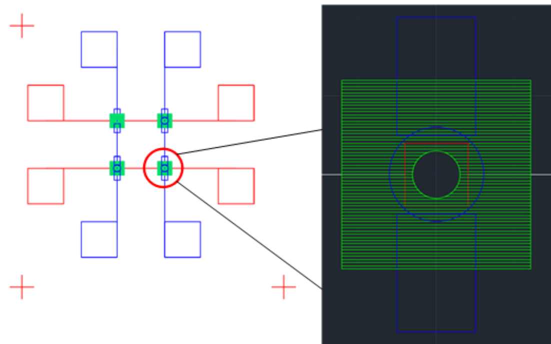
Dr. Lall presented CAVE3 papers on the topics of flexible batteries, and z-axis interconnects in both the 'Power' and 'Reliability-Metrology' tracks at FLEX 2020 in San Jose, CA. The conference hosted sessions that provide important intel from more than 120 industry thought leaders and researchers. Professionals in the flexible, hybrid and printed electronics field will network with customers, industry colleagues, academia, suppliers, and partners, and learn about the latest technology developments. His presentations included:

- Lall, P., Assessment of Flexible Batteries Under Dynamic Folding and Flex-to-Install with Varying C-Rates and Temperatures
- Lall, P., Relationship Between Process Recipe-Print Consistency-Performance for Additively Printed Z-axis Interconnects in Multi-layer Circuits

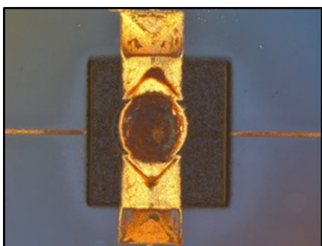
Research Highlights

Additively Printed Multi-layer Circuits with Aerosol-Jet

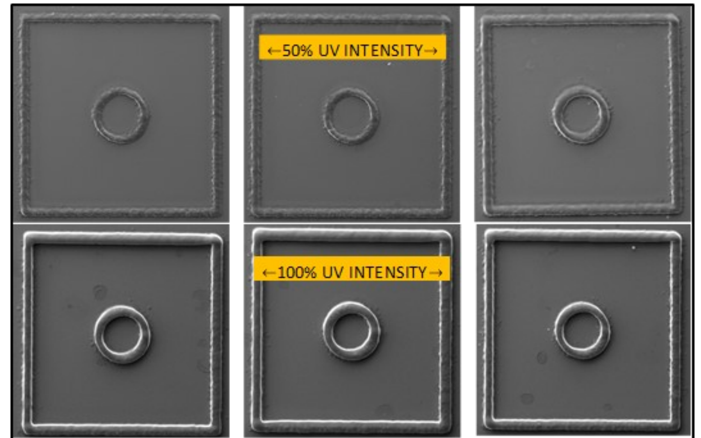
Additive manufacturing of electronics is constantly growing and becoming a new trend in printed electronics applications. Printing technologies such as Aerosol Jet provide the freedom of miniaturizing interconnects and producing fine pitch components. Aerosol Jet, a direct printing technique, replaces the traditional processes, such as lithography and etching, of manufacturing a printed circuit board, which further allows circuits to be fabricated onto different kinds of substrates. Wide impact areas range include healthcare. Wearables, and future automotive applications. Considering the fact that traditional electronics are multi-material, the printing technique needs to be able to easily produce multi-layer circuitry in order to replace traditional electronics. Furthermore, with aerosol printing, there are various parameters involved that need to be controlled to obtain a fine print with low electrical properties. The aerosol jet printer from Optomec is utilized in this study, which consists of two types of atomizers suitable for all types of inks with various viscosities. One type is an Ultrasonic Atomizer, which supports ink with a viscosity range of 1-5cP, and another type is a Pneumatic Atomizer with a large range of suitable viscosity of 1-1000cP. This project focuses on utilizing the aerosol jet technique using both the atomizers to develop process parameters in order to successfully print bi-material, multi-layer circuitry. The insulating material between two conductive lines used in the paper is of a very high viscosity of 350cP, which is suitable for a Pneumatic atomizer and Silver Nano-particle ink with the viscosity suitable for an Ultrasonic atomizer as a conductive ink. A statistical modeling approach is presented to predict the attributes, such as micro-via diameter, before starting the print process, which enables us to pre-adjust the dimensions in CAD for the desired output. Process parameters to obtain a fine print with satisfactory electrical properties and better dimensional accuracy are developed. The importance of pre-cleaning the substrate and the printing process efficiency gauged as a function of process capability index and process capability ratio also are discussed.



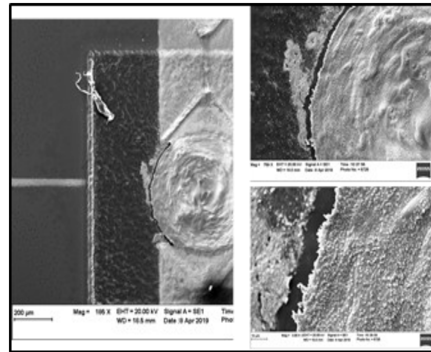
Test Design for Additively Printed Micro-Via w/Z-axis Interconnects



Additively Printed Micro-Via w/Z-axis Interconnects in a 2-layer Substrate



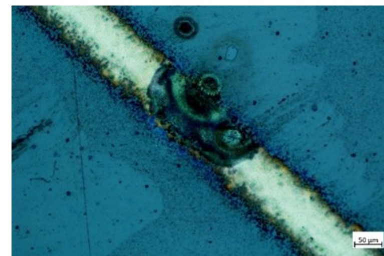
Additively Printed donut-Via using UV sintering during the print-process on aerosol-jet printer.

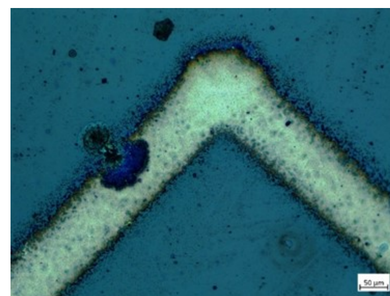


Effect of extended thermal sintering on the silver z-axis interconnect insie a micro-via.

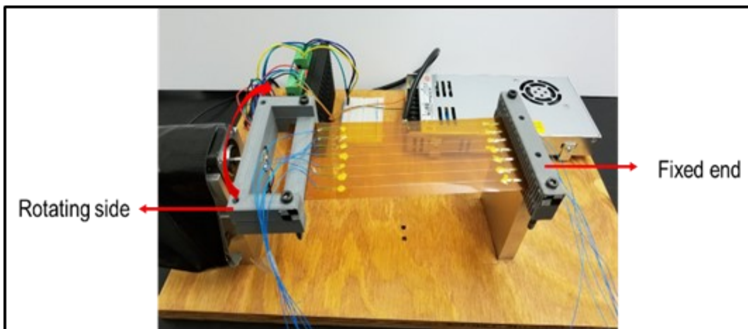
Sweat-Testing of Additive-Printed Flexible Electronics in Flexure and Twist

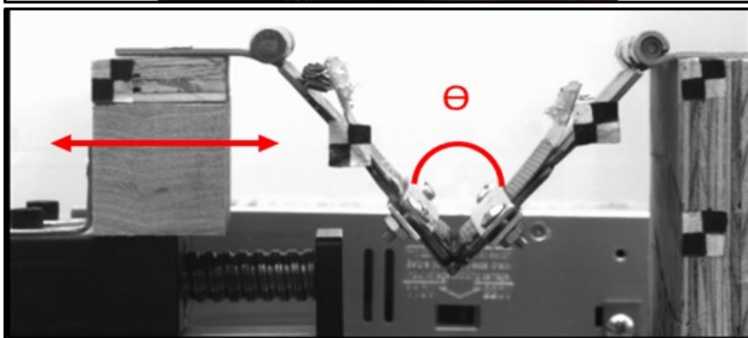
Additively Printed Flexible electronics in wearable applications may be subjected to twisting or flexing in addition to exposure to sweat depending on the form factor and location of use. There is a dearth of standards for the testing and reliability assurance of flexible electronics and reliability data for various use conditions. In this paper, a test protocol has been developed for twisting and flexing on aerosol-jet additively printed flexible circuits. Test patterns with commonly used traces geometries have been developed, aerosol-jet printed, and thermally sintered under various conditions. Moreover, reliability data has been acquired under both twist and flex by utilizing resistance monitoring, and failure mechanisms have been studied for both deformation modes. Two

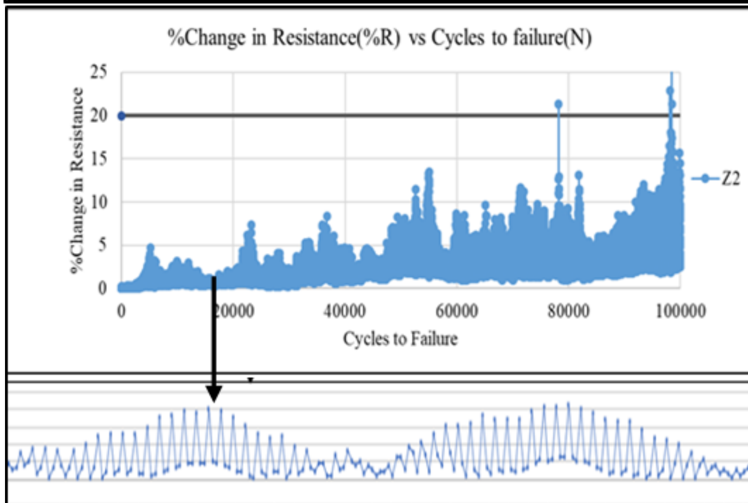




different types of motion including twist and flexing has been studied for the effect of sintering temperature on the printed interconnects. In addition, the effect of sintering on the shear strength of the interconnects has been quantified. Data of resistance and shear load indicates that conductive traces printed with using silver nanoparticle have a lower susceptibility to failure at 250˚C. The cyclic bending test results adds further evidence to the same. It can be observed that with reducing the final angle by 20˚ makes a big difference in the cycles to failure. The samples can sustain more than 100,00 cycles as compared to 8000 cycles in the prior study. The twisting motion too follows a similar trend and can be noticed that the amount of stress induced on the interconnects is much less as compared to the bending motion. It is also evident that the zigzag traces tend to fail early as compared to other geometry reason being the normal stress acting on the trace was higher as compared to other trace geometry. It was also observed that the polyimide substrate too undergoes plastic deformation at the end of 8000 cycles of flexure.

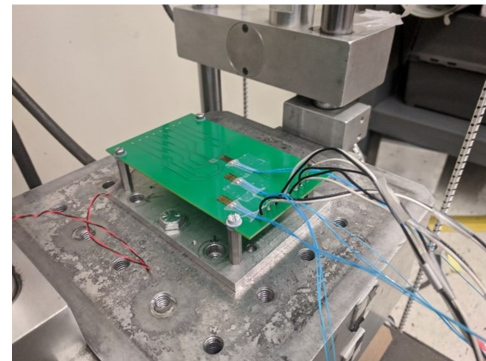




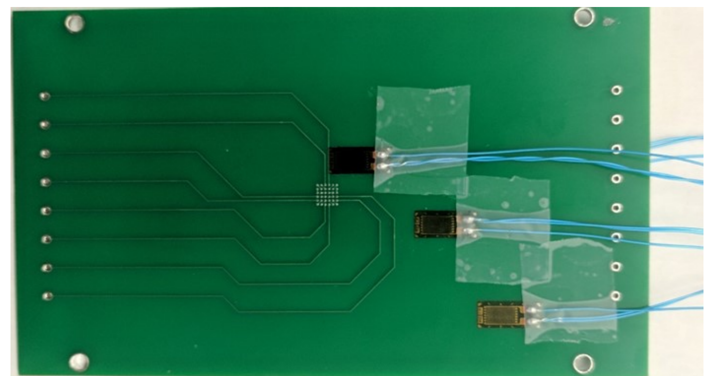


Health Monitoring of PCB's under Shock Loads

The dependence of strain signals in health monitoring under shock is studied by conducting drop experiments on a one package PCB at 3,000 G acceleration levels. The resistance and strain measurements of the PCB are acquired during each drop to analyze the changes in the values during the experiment. Three strain gauges are fixed on the back side and one on the front side of the package to acquire the four strain signals. These four strain gauges are fixed at different locations on the board to measure the changes of the strain values at different positions and to monitor the health of the PCB after each drop. Analysis on the progression of failure was carried out using frequency-based techniques on the strain signals from different locations of the board and failure of the package was identified from the increase in the resistance values of the package during the drop. Feature vectors selected were based on the time-frequency data as well as the logarithmic decrement of the strain signals during the different drops. Different statistical approaches on identifying the changes in the damping characteristics of the package during drop were also utilized Statistical analysis on the changes in the resistance values were quantified in accordance with the changes in the strain and correlation of both were attempted. The dependence on position of the strain gauge on the PCB was also studied by comparing the variation of the feature vectors of the corresponding strain signals. The 'before' and 'after' failure strain signals were compared on the frequency components and the changes in the damping characteristics of the strain signals.



(above) Instrumented Daisy-Chained Board on Drop tower



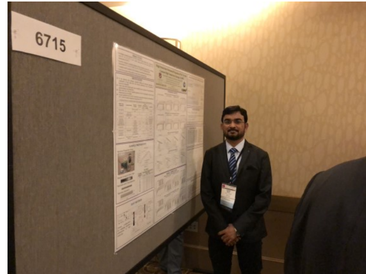
(above) Back side of the test PCB

Announcements

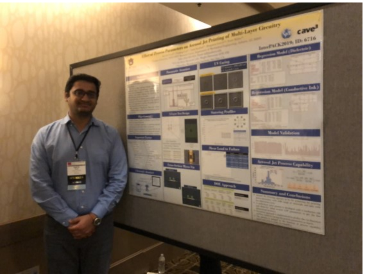
CAVE3 Researchers Present Research-Papers at the ASME INTERPACK 2019 Conference in Anaheim, CA

CAVE3 students attended and presented at the ASME 2019 INTERPACK Conference in Anaheim, CA from October 7-9, 2019. Twenty papers were presented by CAVE3 researchers, and presentations included both oral and poster sessions. A list is included on pages 8-9 of the newsletter.

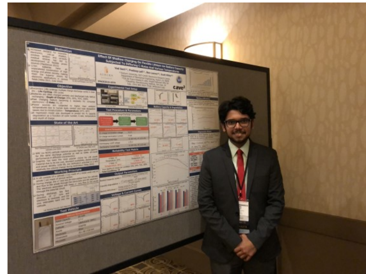
Tony Thomas



Vishal Mehta

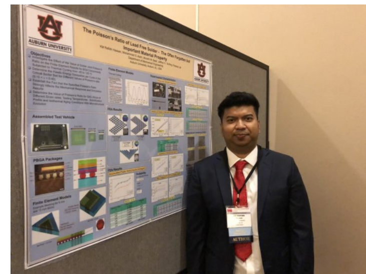


Kartik Goyal

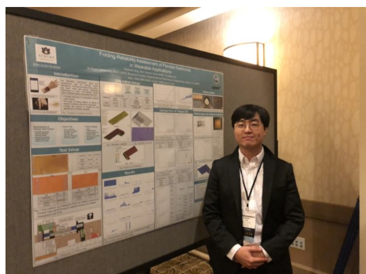


Ved Soni

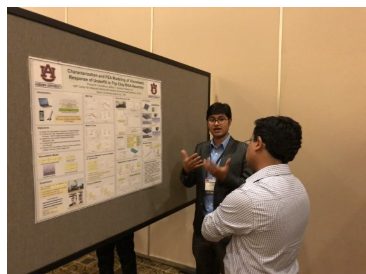
Jinesh Narangaparambil



Rafidh Hassan

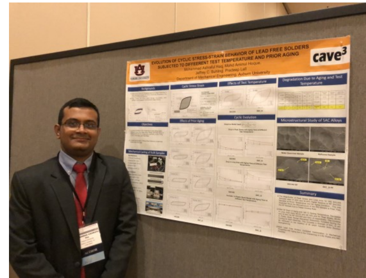


Hyesoo Jang



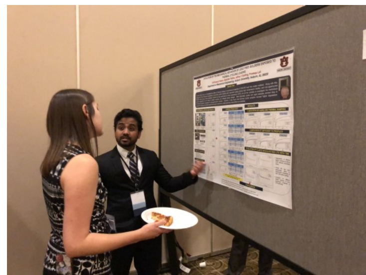
Promod Chowdhury

The papers presented touched on a number of cutting-edge topics in the general area of harsh environment electronics presenting breakthrough findings in modeling, reliability, testing and life-prediction of electronic systems. The CAVE3 team from Auburn University presented their research on additively printed flexible electronics manufacturing process development and test protocols. AU-CAVE3 has a full suite of tools for additively printed flexible electronics using aerosol-jet, screen printing, dispense-on-demand printing and ink-jet printing. In addition, CAVE3 has established itself as one of the leaders in the design and testing of flexible hybrid electronics.

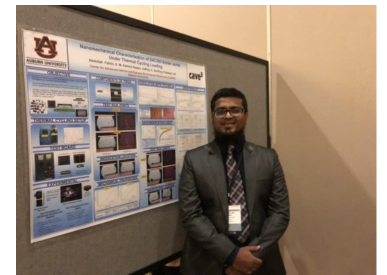


Ashraful Haq

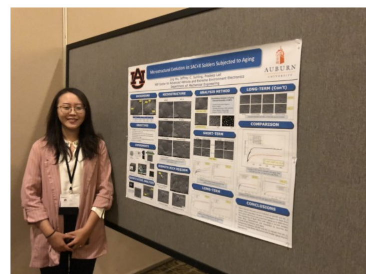
Kalyan Dornala



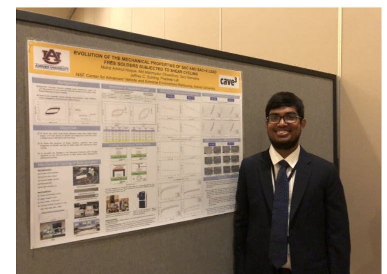
Kamrul Hassan



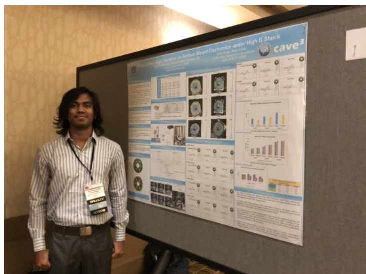
Abdullah Fahim



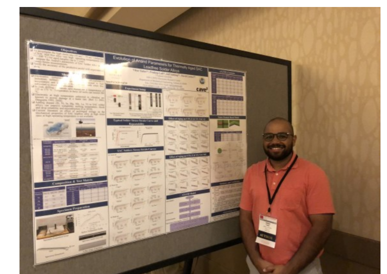
Jing Wu



Aminul Hoque



Aathi Pandurangan



Vikas Yadav

Professor Lall served as a panelist for a panel on the topic of “Reliability in the Age of AI: Opportunities and Challenges”. Other panelists included Mohak Shah from LG Electronics, Przemek Gromala from Bosch, and Anna Prakash from Intel. In addition, Professor Lall chaired the Session 4-3 on Flexible Electronics Packaging and Assembly.

Announcements

CAVE3 Researchers win Top-Honors at the ASME INTERPACK 2019 Conference in Anaheim, CA

The following was recognized as Outstanding-Paper of Conference Award at the ASME INTERPACK 2019

Lall, P., Narangaparambil, J., Leever, B., and Miller, S., Flexure and Twist Test Reliability Assurance of Flexible Electronics, ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (ASME INTERPACK 2019), Anaheim, CA, pp. 1-10, October 7-9, 2019

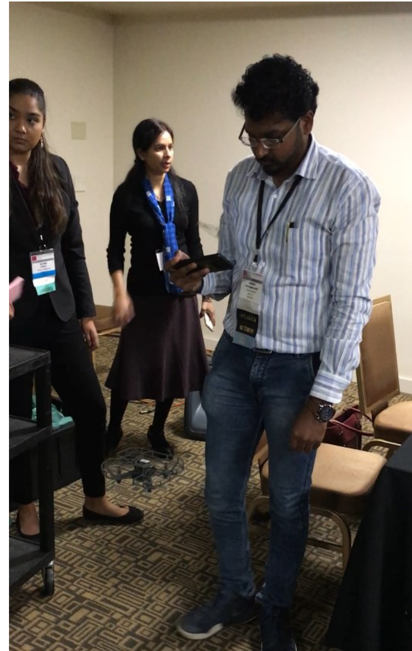
Left-to-Right: Ben Leever (US AFRL), Jinesh Narangaparambil (AU), Pradeep Lall (AU) receiving the'Outstanding Paper Award' ASME InterPACK 2019 in Anaheim, CA.

CAVE3 Researchers Attend and Present at SMTAI 2019

Dr. Lall and Dr. Hamasha Chaired Sessions and Presented Papers at SMTAI 2019 from September 22-26, 2019:

X-Ray Microcomputed Tomography Based FE-Models to Capture Realistic Manufacturing Variability in Cu-Al Wirebonds and Solder-Joints in QFNs, Lall, P., Kasturi, M., Kothari, N., and Locker, D., Proceedings of SMTAI, pp. 1-13, Sept 22-26, 2019;

Effect of Cure Conditions on the Interface Properties and Reliability of Potted Electronics in 25,000g Mechanical Shock, Lall, P., Dornala, K., Lowe, R., Deep, J., Proceedings of SMTAI, pp. 1-10, Sept 22-26, 2019;



Thermal Cycling Reliability of Newly Developed Lead-Free Solders for Harsh Environments, Sa'd Hamasha, Proceedings of SMTAI, Sept 22-26, 2019

Microstructure and Mechanical Properties of SAC-Bi Solder Alloys with Aging, Sa'd Hamasha, Proceedings of SMTAI, Sept 22-26, 2019

Jinesh Narangaparambil test-flies (Left) the smartphone-operated drone while Aathi Pandurangan films (Below) at ASME InterPACK 2019

Dr. Lall (center) with CAVE3 Ph.D. Students (front row: left to right) Hyesoo Jang, Ved Soni, Vishal Mehta, Jinesh Narangaparambil, Vikas Yadav, Aathi Pandurangan, Tony Thomas (back row: left to right), Kalyan Dornala, and Kartik Goyal at InterPACK 2019

Lall Receives MacFarlane Distinguished Professorship

On October 23, 2019, Dr. Lall was awarded a prestigious 'Distinguished Professorship' in the Department of Mechanical Engineering by Auburn University Provost Bill Hardgrave and Samuel Ginn College of Engineering Associate Dean for Research Steven Taylor.

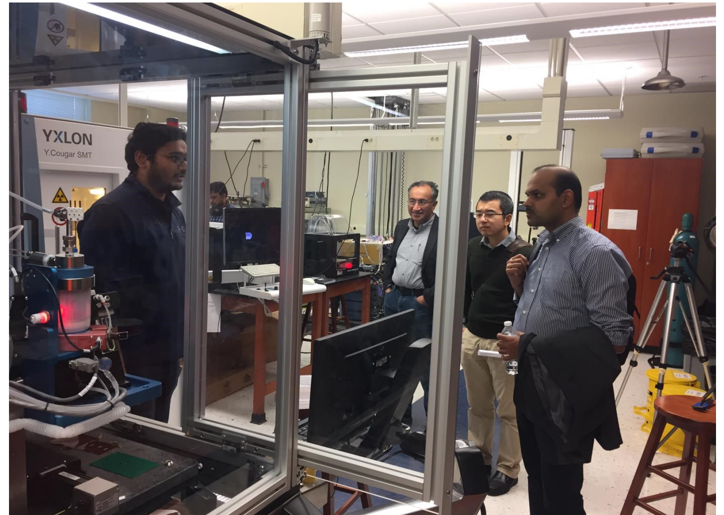
Dr. Lall (center) with Auburn University Provost Bill Hardgrave (right) and College of Engineering Associate Dean for Research Steven Taylor (left)

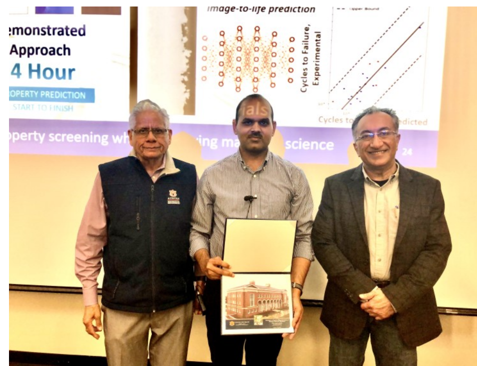
Dr. Hamasha Receives Prestigious IPC Teaching Award

On December 11, 2019, CAVE3 faculty member and Auburn University Industrial and Systems Engineering professor Dr. Sa'd Hamasha received the 2019 Michael V. Carano Teacher Excellence Award from the IPC (the Association Connecting Electronics Industries). This award is the most prestigious award that IPC gives to recognize educators and instructors who enrich the lives of students interested in a career path in the electronics industry. There is only one awardee per year.

GE Research Visits Department of Mechanical Engineering and CAVE3

On October 25, 2019, the Department of Mechanical Engineering hosted a seminar entitled 'Advances in Additive Manufacturing at General Electric', during which Dr. Vipul Gupta discussed the current technological advances and research progress that he and his colleagues are making at GE Research. Dr. Gupta visited the CAVE3 Research Labs to view research in additive printed electronics. He has been leading efforts to combine physics with artificial intelligence and machine learning to advance alloy design, AM processing, sensors and analytics, and post-production inspection; and transitioning these technical developments into real GE products.





(Top) Left-to-Right Kartik Goyal (AU), Pradeep Lall (AU), Xiaoyuan Lou (AU), Vipul Gupta (GE)

(Left) Drs. Pradeep Lall and P.K. Raju meet with Dr. Vipul Gupta following the seminar

Dr. Gupta is a Senior Materials Scientist in the Structural Materials Organization at GE Research in Niskayuna, NY. He received his PhD in Materials Science and Engineering from the University of Virginia and his B.S. and M.S. degrees from IIT Bombay in India. He joined GE Research in 2014, and has been actively working on metal additive manufacturing (AM) for the past 3 years. Before Dr. Gupta was employed at GE Research, he served as a resident researcher at the NASA Langley Research Center in Hampton, VA.

CAVE3 PhD Student Wins Best Poster Award at Mechanical Engineering Conferences

CAVE3 Doctoral Candidate Nakul Kothari won the 'Best Poster Award' at the Auburn University Department of Mechanical Engineering's 16th Annual Elements of Mechanical Engineering Conference, which occurred from September 30-October 1, 2019. His poster is entitled "Analysis of Progressive Damage in Fuze Electronics using Micro-Computed Tomography and Finite Element Models".

Selected Recent Publications

1. Lall, P., Mehta, V., Suhling, J., and Locker, D., *High Strain Rate Mechanical Properties of SAC-Q with Sustained Elevated Temperature Storage at 100°C*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-12, October 7-9, 2019.
2. Lall, P., Soni, V., Abrol, A., Leever, B., and Miller, S., *Effect of Charge-Discharge Depth and Environment Use Conditions on Flexible Power Sources*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-9, October 7-9, 2019.
3. Lall, P., Goyal, K., Kothari, N., Leever, B., and Miller, S., *Effect of Process Parameters on Aerosol Jet Printing of Multi-Layer Circuitry, and Environment Use Conditions on Flexible Power Sources*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-10, October 7-9, 2019.
4. Lall, P., Narangaparambil, J., Leever, B., and Miller, S., *Flexure and Twist Test Reliability Assurance of Flexible Electronics*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-10, October 7-9, 2019.
5. Lall, P., Thomas, T., Yadav, V., Narangaparambil, J., and Liu, W., *Acceleration Factors for Flexible Electronics in Wearable Applications From Actual Human Body Measurements*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-9, October 7-9, 2019.
6. Lall, P., Jang, H., Leever, B., and Miller, S., *Folding-Reliability of Flexible Electronics in Wearable Applications*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-8, October 7-9, 2019.
7. Chen, J., Jaeger, R.C., and Suhling, J.C., *Piezoresistive Theory for 4H Silicon Carbide Stress Sensors on Four-Degree Off-Axis Wafers*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-8, October 7-9, 2019.
8. Ahmed, T., Motalab, M., and Suhling, J.C., *Numerical Investigation on Electromigration Oriented Failure of Lead Free Solder Joints With Aging Effects*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-8, October 7-9, 2019.
9. Lall, P., Yadav, V., Suhling, J., and Locker, D., *Evolution of Anand Parameters With Elevated Temperature Aging for SAC Leadfree Alloys,* Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-16, October 7-9, 2019.
10. Lall, P., Thomas, T., Suhling, J., and Blecker, K., *Health Monitoring of PCB's Under Mechanical Shock Loads,* Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-7, October 7-9, 2019.
11. Fahim, A., Hasan, K., Suhling, J.C., and Lall, P., *Nanoindentation Testing of SAC305 Solder Joints Subjected to Thermal Cycling Loading*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-11 October 7-9, 2019.
12. Fahim, A., Hasan, K., Suhling, J.C., and Lall, P., *Nanoindentation Testing of SAC305 Solder Joints Subjected to Thermal Cycling Loading,* Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-11 October 7-9, 2019.
13. Chowdhury, M., Hoque, M..A.., Suhling, J.C., Hamasha, S., and Lall, P., *Evolution of the Microstructure of Lead Free Solders Subjected to Both Aging and Cyclic Loading*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-11, October 7-9, 2019.
14. Chowdhury, M., Hoque, M..A.., Suhling, J.C., Hamasha, S., and Lall, P., *Evolution of the Microstructure of Lead Free Solders Subjected to Both Aging and Cyclic Loading*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-11, October 7-9, 2019.
15. Chowdhury, P.R., Suhling, J.C., and Lall, P., *Modeling of Underfilled PBGA Assemblies Using Both Viscoelastic and Elastic Material Properties*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-10, October 7-9, 2019.
16. Haq, M.A., Hoque, M.A., Suhling, J.C., and Lall, P., *Effects of Test Temperature and Prior Aging on the Cyclic Stress-Strain Behavior of Lead Free Solders*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-10, October 7-9, 2019.
17. Hasan, K., Fahim, A., Suhling, J.C., Hamasha, S., and Lall, P., *Effect of Thermal Cycling on the Mechanical and Microstructural Evolution of SAC305 Lead-Free Solder*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-12, October 7-9, 2019.
18. Hoque, M.A., Chowdhury, M.M., Hamasha, S., Suhling, J.C., and Lall, P., *Effects of Shear Cycling on the Mechanical Properties of SAC and SAC+X Lead Free Solder Joints*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-11, October 7-9, 2019.
19. Wu, J., Alam, M.S., Suhling, J.C., and Lall, P., *Investigation of the Effects of High Temperature Aging on Mechanical Behavior and Microstructural Changes in Lead Free Solders*, Proceedings of the ASME 2019 International Technical ence and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1

Interfaces Under Flexure Loading, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-6, October 7-9, 2019.

21. Lall, P., Pandurangan, A., Dornala, K., Suhling, J., Deep, J., and Lowe, R., *Effect of Drop Angle Variation and Restraint Mechanisms on Surface Mount Electronics Under High G Shock*, Proceedings of the ASME 2019 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems (InterPACK2019), Anaheim, CA, pp. 1-12, October 7-9, 2019.
22. Lall, P., Kasturi, M., Kothari, N., and Locker, D., X-Ray Microcomputed Tomography Based FE-Models to Capture Realistic Manufacturing Variability in Cu-Al Wirebonds and Solder-Joints in QFNs, Proceedings of SMTA International, Rosemont, IL, pp. 1-13, September 22-26, 2019.
23. Lall, P., Dornala, K., Lowe, R., and Deep, J., Effect of Cure Conditions on the Interface Properties and Reliability of Potted Electronics in 25,000G Mechanical Shock, Proceedings of SMTA International, Rosemont, IL, pp. 1-11, September 22-26, 2019.
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26. Thermal Cycling Reliability of Newly Developed Lead-Free Solders for Harsh Environments, Francy John Akkara, Cong Zhao, Sudan Ahmed, Mohammed Abueed, Sinan Su, Sa’d Hamasha, Jeffrey Suhling, Pradeep Lall, Proceedings of SMTAI, pp. 1-8, Sept 22-26, 2019;
27. Mechanical Properties of SAC-Bi Solder Alloys With Aging, Mohamed El Amine Belhadi, Dr. Luke Wentlent, Raed Al Athamneh, Sa’d Hamasha, Proceedings of SMTAI, pp. 1-13, Sept 22-26, 2019;

Auburn University
CAVE3
Samuel Ginn College of Engineering
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Auburn, AL 36849

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