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CENTER FOR ADVANCED LIFE CYCLE ENGINEERING (CALCE)
WWW.CALCE.UMD.EDU, TEL: 301-405-5323

INSIDE

Mission Statement

To develop scientifically-based, innovative methodologies that decrease life-cycle risks for the next generation of electronic products and systems, and to create and maintain an educational and technology transfer infrastructure for their rapid dissemination and utilization.

Message from the Director

Education is a core tenet of our mission at CALCE. Our faculty and staff provide comprehensive M.S. and Ph.D. programs in the area of reliability, maintainability and availability at the University of Maryland, one of the few universities to offer specialization in the life-cycle design, management, and sustainment of electronic products and systems.

Originally developed with the aid of $6M from the ARPA Technology Reinvestment program, CALCE offers 14 unique graduate courses and various research opportunities in the areas of physics-of-failure, prognostics and health monitoring, reliability testing and analysis, cost analysis, and parts selection/management. Together, CALCE and UMD are bringing cutting-edge research into the classroom to provide students with a critical knowledge base and fundamental skill sets.

Since 1987, over 240 students have graduated with graduate degrees specializing in electronic products and systems, with many alumni pursuing successful careers at major domestic and international companies—including Intel, Apple, Samsung, Microsoft, Dell, LG, Huawei, Schlumberger, Honeywell, General Electric, AMD, and Boeing—and in academia.

Unlike conventional educational programs, CALCE invests in the development of human capital through a variety of partnerships, research opportunities, exchange programs, and internships, including:

- Educational and research partnerships with institutions around the world. including the City University of Hong Kong, Yokohama National University in Japan, Cranfield University and the University of Greenwich in the UK, Korea Advanced Institute of Science and Technology, and the Technical University of Denmark.

- Long-term research projects where professionals from industry leaders—such as Honeywell, Boeing, Airbus, Hitachi, Toshiba, Dell, Samsung, Microsoft, Huawei, Ericsson, and Emerson—participate in research valuable to both CALCE and industry.

- Exchange programs that welcome graduate students from domestic and international universities, including Michigan Technological University, the University of Birmingham, and Nanjing University of Aeronautics and Astronautics. We also regularly host non-thesis exchange students from several international universities, including the Petroleum Institute (Abu Dhabi), the University of Mannheim (Germany), the American University of Beirut, the City University of Hong Kong, the Indian Institutes of Technology, and the National Institutes of Technology (India).

- Participation in the combined B.S./M.S. program within the Department of Mechanical Engineering at the University of Maryland. This highly competitive program allows B.S. students to begin work on their Masters research as early as their junior year and potentially finish both a B.S. and M.S. in five years. CALCE offers students in the program the opportunity to perform hands-on research in our world-class laboratories.

- Year-long internships for local high school students who are mentored by our faculty and are often recruited as undergraduate science and engineering students. Several of these students have won local, regional, and national science competitions based on the work they have performed at CALCE.

- Education programs for practitioners in industry in the form of monthly web-based seminars, onsite and online short courses, and through organizing and hosting symposia, conferences, and workshops. Popular topics include prognostics and systems health management, counterfeit parts management, obsolescence management, physics of failure, accelerated product testing and qualification, and supply-chain management.

Over the past 25 years, CALCE has vastly expanded the scope and impact of its basic and applied research while receiving notable recognition for our efforts, including the ARL Director's Award for effective educational and technology transfer strategies, the Technology Innovation Award from the National Science Foundation (2008), and the General Thomas R. Ferguson Jr. Systems Engineering Excellence Award from the National Defense Industrial Association (2009). From developing new industry standards, industry roadmaps, and improved management practices to creating powerful software-based design tools, analysis methodologies, and databases, CALCE is significantly influencing industry and academia on a global scale.

Michael Pecht

Michael Pecht Ph.D., PE
George Dieter Chair Professor
Director of CALCE

Pecht Receives 2010 ISRMS Lifetime Achievement Award

Professor Michael Pecht and Dr. Anil Kakodkar (Former Chairman of the Indian Atomic Energy Commission & Secretary of the Department of Atomic Energy), were honored by the Indian Society of Reliability, Maintainability and Safety with the society's first ever Lifetime Reliability Achievement Awards on December 16, 2010.

This is the highest reliability award of its kind in India. Pecht received the award for his "significant contributions in the area of product reliability, prognostics & health management of electronic components." Pecht has also received the Lifetime Achievement Award from the IEEE Reliability Society (2007). For more information, please contact Professor Pecht at pecht@calce.umd.edu.

CALCE Electronic Products and Systems Consortium Spring Technical Review Meeting - March 22-23

The CALCE Electronic Products and Systems Consortium (EPSC) will hold its Spring Technical Review and Project Planning Meetings from March 22-23, 2011, at the University of Maryland's College Park campus. The meetings will allow EPSC members to review current year (FY11) research findings and discuss next year's (FY12) research projects.

The agenda for this event will be available at www.calce.umd.edu, under Upcoming Events.

The following projects will be presented at the meeting:

- PoF Models for Combined Vibration Fatigue and Temperature Cycling in SAC Assemblies
- PoF Models for Multiaxial Vibration Fatigue
- Influence of Aging on Viscoplastic Behavior and Fatigue Durability of SAC105X
- Whisker Farm Growth Measurements
- Electrical Apects on Tin Whisker Failures
- PoF Model of Conformal Coating against Tin Whisker Growth: Performance Evaluation under Operating and Storage Conditions
- Impact of Power Cycling on Lead-free Solder Reliability
- Evaluation of New Printed Wiring Board Finishes: ENEPIG
- Long-term Vibration Fatigue Life of Pb-free Interconnects
- Intermittent Failures in Tantalum Capacitors
- Evaluation of End-of-Repair Dates for Electronic Assemblies
- Physics-of-Failure PoF Qualification of Complex Lighting Products
- Electronic Component Failure Categorization under Extreme G Loading
- Physics-of-Failure PoF Qualification of Optical Disk Drives
- Application Requirements and PoF Modeling Using RF Impedance Monitoring
- Impact of Extended Dwells on Solder Interconnect Reliability of New Low Silver Lead-free Solders
- Reliability Test and Analysis of MEMS Sensors
- Lifetime Distributions of Aluminum Electrolytic Capacitors
- Adhesion Strength of Advanced Polymer Films for Flexible and Rigid Substrates
- Analysis of Advanced EMC/PCB and EMC/Chip Delamination
- Throwaway Electronics Phase II – Industry-Level Analyses
- Electronic Part Sourcing Management under Supply Chain Uncertainty in Long Life Cycle Systems
- Degradation Analysis of Lithium Ion Batteries
- Reliability Test and Analysis of MEMS Commercial Off the Shelf
- Reliability of Copper Traces Under Cyclic Bending
- PoF Models for Drop Qualification of Portable Products
- Building in Reliability in Thermal Management
- High Temperature Solder System for Improved Reliability
- PoF Models for Electronics in Long-Life Lighting Products

This event is free for CALCE EPSC members, and all current CALCE EPSC members are invited to attend. Invited guests pay a $1,500 USD registration fee. Non-EPSC organizations interested in joining CALCE and attending the Spring Technical Review should contact Michael Osterman at osterman@calce.umd.edu. For more information on CALCE EPSC, please visit **www.calce.umd.edu/consortium.html.**

EPSC Members Honored at Fall Technical Review

Mike Davisson, Agilent Technologies

Longtime CALCE Electronic Products and Systems Consortium (EPSC) members Mike Davisson (Agilent Technologies) and Dave Humphrey (Honeywell International) were honored by the EPSC for their many contributions to CALCE research at last fall's EPSC Technical Review. EPSC director Michael Osterman presented Humphrey and Davisson with EPSC Contributor Appreciation Awards during the opening activities of the Fall Technical Review. Together, Davisson and Humphrey have contributed over twenty years of intellectual and research support to CALCE EPSC and its research program. As they transition to new opportunities, both have promised to maintain contact with CALCE EPSC staff and students, using their experience to continually guide the innovative and talented researchers and students at CALCE.

CALCE welcomed representatives from a number of public and private industry leaders—including Honeywell, U.S. Army, Rockwell Automation, Lockheed Martin, and more—to the two-day event. CALCE investigators and students presented the latest findings from FY10 projects and addressed critical issues in electronic products and systems, including tin whisker mitigation, MEMS reliability, physics-of-failure-based qualification and lead-free solder applications. At the conclusion of daily presentation schedules, attendees participated in tours of the CALCE facilities—including in-depth looks at the Microanalysis, Microelectronics, Optomechanics, and Permanent Interconnects Laboratories.

Dave Humphrey, Honeywell International

CALCE also kicked off the FY11 research year at the Fall Technical Review by introducing a new slate of projects, including solder interconnect durability with ENEPIG surface finish, failures in Tantalum capacitors, life assessment of electrolytic capacitors, life cycle cost evaluation of end-of-repair dates for electronic assemblies, and evaluation of temperature cycle interconnect reliability of low silver lead-free solders. CALCE investigators and students will provide mid-year reports on FY11 projects at the Spring Technical Review, scheduled for March 22-23, 2011, where more innovative solutions to 21st century challenges in electronic products and systems will be revealed. For more information on the EPSC Technical Reviews, please contact Michael Osterman at osterman@calce.umd.edu.

CALCE Showcases Rapid Reliability Assessment at SARA® Workshop - March 21

CALCE EPSC Director Michael Osterman will lead a one-day workshop on the center's one-of-a-kind physics-of-failure-based simulation assisted reliability assessment software, SARA®, on March 21, 2011. The CALCE SARA® software uses physics-of-failure principles to assess whether an electronic part or system can meet defined life cycle requirements. CALCE SARA® software is used to support the CALCE Design for Reliability (DfR) assessment process, which allows design engineers to rapidly make design changes and assess the impact of product reliability. The software can also be used to assess the life expectancy of electronic hardware under anticipated life cycle loading and accelerated stress test conditions. The SARA® workshop will include a tutorial session followed by a comprehensive review of the software's newest features. Registration is free to CALCE EPSC consortium members. For more information, please contact Michael Osterman at osterman@calce.umd.edu.

PHM Fall Technical Review a Success; Spring Meeting Scheduled - March 24

The CALCE PHM Group recently completed its Fall 2010 Technical Review, where the group addressed current issues in prognostics and health management (PHM) of electronics. The three-day event, held October 19-21, 2010, at CALCE headquarters on the University of Maryland's College Park campus, included a two-day short course on PHM methods followed by a one-day review of the PHM group's current research activities. Attendees of the two-day short course participated in lectures, discussions, and interactive exploration sessions on failure prediction, physics-of-failure (PoF) methodologies, canaries for PHM, and fusion prognostics with PHM group investigators and students.

Following the two-day short course, members of the CALCE Prognostics and Health Management Consortium received an inside look at the latest findings from the PHM Group's research activities at the PHM Fall Technical Review. PHMC members witnessed over fifteen presentations by PHM faculty, investigators, and students on a range of topics, including PHM implementation, PHM for LED lighting systems, prognostics of insulated gate bipolar transistors (IGBT), and PHM for RF-MEMS.

Attendees were enthusiastic about the findings, with many eager to participate in the PHM Group's next Technical Review, scheduled for March 24, 2011. The Spring Technical Review will bring attendees more innovative research and insight into the future of PHM applications. For more information on the PHM Group and the Fall Short Course/Technical Review Event, please contact Nikhil Lakhkar at nlakhkar@calce.umd.edu.

PHM Group Welcomes New Faculty Member, Consortium Director

The CALCE PHM Group welcomed new faculty member and PHM Consortium director, Nikhil Lakhkar, last summer. Lakhkar received his M.S. and Ph.D. in Mechanical Engineering from the University of Texas at Arlington. His research interests include prognostics and health management, lead-free product reliability, and high heat flux cooling of electronics. During his studies at UT Arlington, he worked at IBM's Advanced Thermal Laboratories in Poughkeepsie, NY, and Maxim Integrated Products, Dallas, TX. His technical publications include papers on thermal management, lead-free electronics, and thermoelectrics. For more information on Lakhkar and his work with the CALCE PHM Group, please contact him at nlakhkar@calce.umd.edu.

CALCE PHM Methods Predict Li Battery Aging

Because of their high energy densities and long life, lithium-ion batteries are a popular solution for the energy storage demands of cell phones, portable devices, space and aircraft power systems, stationary power storage, and electric and hybrid electric vehicles. However, from the day the battery is manufactured, it begins to degrade (also known as aging), either with charge-discharge cycling or under storage.

Capacity fade, power fade, and internal resistance increase are the three main effects of degradation. The degree of degradation is usually affected by the battery's operating temperature, depth of discharge, discharge rate, cycle profile, and storage time and conditions. Prognostic methods can predict remaining useful life (RUL) under various environmental conditions and different charge cycling profiles. Advance notice of maintenance or replacement can be given when battery life arrives at a certain stage or at a certain percentage of charge. Prognostics is a critical function for industrial applications (e.g., spacecraft) and a product differentiation point for commercial applications (e.g., mobile phones and electric vehicles).

CALCE employs a fusion prognostic method that takes advantage of physics-of-failure approaches and data-driven algorithms to improve the accuracy of lifetime and RUL predictions. For more information on CALCE Prognostics methods and li battery aging prediction, please contact Michael Osterman at osterman@calce.umd.edu.

Pecht Delivers Keynote Speech at CMMIF

Professor Michael Pecht delivered a keynote speech, "Self Cognizant Systems – Innovation for the Future," at the 7th China Manufacturing Management International Forum (CMMIF) on October 29, 2010. Nearly 2000 people attended the conference, held in Tianjin, China, including CEOs and presidents from some of the world's leading companies.

CMMIF is supported by top industry professionals and maintains a strong reputation due to its heavy involvement with industry leaders as well as its timely, practical lectures. CMMIF has greatly contributed to world manufacturing by bridging communication between the Chinese manufacturing community and their peers around the world. For more information, please contact Professor Pecht at pecht@calce.umd.edu.

CALCE and ARL Begin PHASE II of Autonomous Prognostic Monitoring Device Project

To predict the remaining useful life of critical devices, components, and sub-systems on a multitude of U.S. Army platforms, CALCE proposed the development of an autonomous prognostic monitoring device with the following attributes: a small form factor, low power consumption, wireless data transmission, and the ability to integrate with existing diagnostics and sensors. In March 2009, CALCE was awarded a contract by the U.S. Army Research Laboratory (ARL) to develop such an autonomous monitoring device. CALCE has teamed up with Texas-based ePrognostics LLC to develop this system for ARL.

The CALCE-ePrognostic sensor system is a novel monitoring device that can monitor multiple parameters used for prognostics, including, but not limited to, temperature, humidity, vibration, shock, and external sensors. This system provides wireless transmission and can be mounted in the host system easily and nonintrusively. It is compatible with an open common architecture, enabling ARL to use their software algorithms and incorporate existing shock and future sensors developed for environmental and operations profiling.

The new system will have the processing efficiency necessary to expedite operational and logistical decision making without severely impacting physical and logistical footprint. Additional features will include active RFID writeable and readable functions with adjustable distance to optimize RF range, expandable memory storage (load-stress readings and date-time), open system with flat access to data, user programmability (delayed start, date and time, programmable data collection modes including continuous logging, threshold logging, minima/maxima logging), mountable in various modes including an adhesive, and reusable manners (multiple data collection and retrieval cycles).

In July 2010, Phase II of the project was approved by the U.S. Army. For more details, contact Professor Michael Pecht at pecht@calce.umd.edu.

CALCE to Co-organize Prognostic and Systems Health Management Conference - China

Date: May 24-25, 2011; Venue: Shenzhen, China

General Chair: Prof. Michael Pecht; Organizer: IEEE Reliability Society

The 2011 Prognostics and System Health Management Conference (PHM-2011) will be held in Shenzhen, China, on May 24-25, 2011. The PHM-2011 conference will continue to promote the adoption and application of PHM in the Asia-Pacific region. CALCE is a co-organizer of this conference, which aims to bring together a global community of PHM experts from industry, academia, and government—with experience in diverse application areas such as avionics and aerospace, marine systems, power and electronic systems, process industries, computers and telecommunications, material systems, industrial automation, and healthcare and medical technology—to share in PHM development. Researchers and professionals from academia, industry, and government organizations are invited to submit papers. For more details, visit www.cityu.edu.hk/phmc or contact Professor Michael Pecht at pecht@calce.umd.edu.

CALCE Investigates Impact of Contamination on IT and Telecom Equipment Reliability

Data centers account for nearly 14% of the information and communication technology industry's greenhouse gas emissions. Accordingly, the operating conditions of complex electronic systems used in the communication and information industries are more severe than they used to be. With the continuous reduction of the pitch size of electronic components and the feature size and spacing of printed circuit boards, electronics have become more and more sensitive to contamination, especially under uncontrolled temperature and humidity conditions. Contamination, including both gaseous and particulate pollution, can cause mechanical and electrical failures of electronics.

At elevated temperature and humidity, different failure modes and failure mechanisms associated with gaseous and particulate contamination may be accelerated. For example, sulfur-bearing gases are known to be very corrosive. It has been found that sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) can cause corrosion of silver metallization and board finishes by the formation of silver sulfide (Ag_2S). In addition, there can be significant synergistic effects between gases. It has been reported that H_2S alone is not corrosive to silver, but the combination of hydrogen sulfide and nitrous oxide is very corrosive to silver. Similarly, neither sulfur dioxide nor nitrous oxide alone is corrosive to copper, but together they attack copper at a high rate.

A variety of methods have been developed over the years to study the effects of gaseous contamination. The mixed flowing gas (MFG) test is one example. There also exist many industry standards from institutions such as Battelle, IBM, the International Electro-technical Commission (IEC), the Electronic Industries Alliance (EIA), and Telcordia. Among industry standard MFG testing conditions, the Telcordia outdoor conditions were found by CALCE to be the most effective for inducing and promoting creep corrosion on plastic encapsulated microcircuits. Indoor and outdoor operating conditions cannot be precisely defined because a variety of atmospheric variables are present due to seasonal, geographical, natural, and human influences. The concentration of indoor pollutants in a communication and information technology facility is a function of outdoor pollutant levels and indoor generation rates. Thus, indoor values can be greater or less than outdoor values depending on local sources and air conditioning strategies. The compositions of dust particles may also vary based on time and location. The weight percentage of inorganic compounds in indoor dust particles are typically about 70%, and the rest consists mainly of organic compounds and black carbon. The inorganic compounds contain at least 24 kinds of substances. About 4% of the inorganic compounds are water-soluble salts. The major cations and anions are K+, Na+, Ca_2+, Mg_2+, Cl-, F-, NO_3-, and [SO4]2-, respectively.

Airborne dust particles can affect the reliability of electronic equipment in different ways. Dust accumulation on the heat sink, power connectors, or active devices can cause overheating. Dust particles can increase friction on contacting surfaces, thus promoting third body wear and fretting corrosion, which can change the contact resistance. Dust particles act as dielectric materials to induce signal interference in the contaminated signal connectors and lines. Dust is known to enhance moisture absorption on surfaces through capillarity and the hydroscopic nature of common particulate pollutants. This can reduce the threshold humidity levels at which corrosion and ion migration are likely to occur. Furthermore, dust contamination can introduce ionic species to board surfaces, combining with absorbed moisture to promote creep corrosion and electrochemical migration on printed circuit boards or surface-mounted components.

CALCE is currently researching the effects of airborne dust particles on electronics reliability. It is believed that dust particles can increase electrochemical reactions by different means, such as direct or indirect effects on metals, the formation of nuclei of condensation, and the influence on capillary condensation. The problem of how the dust contamination participates in and accelerates corrosion will be the subject of systematic examination by CALCE in the coming months. For more information, please contact Professor Michael Pecht at pecht@calce.umd.edu.

TSFA Director to Host PCB Analysis Workshop at 2011 IPC APEX EXPO

CALCE Test Services Director Bhanu Sood will be a featured presenter and workshop leader at the 2011 IPC APEX Convention, to be held April 10-14 at the Mandalay Bay Resort in Las Vegas, Nevada. Mr. Sood will lead a workshop on "Controlling Moisture Content in Printed Circuit Boards" as part of the conference's professional development series.

The workshop will include a refresher on PCB fabrication; a discussion of the moisture diffusion process, governing diffusion models, and dependent variables; and an examination of moisture effects on PCBs (epoxy matrix, interfaces, vias, traces, solder masks, overcoats). PCB material handling and storage guidelines will also be provided during the workshop. For more information, please contact Bhanu Sood at bpsood@calce.umd.edu.

Short Course on Failure Analysis of Electronics

Date: April 26-29, 2011; Venue: CALCE Failure Analyis Labs, Unversity of Maryland

CALCE and Buehler are pleased to offer an intensive 4-day course on Failure Analysis of Electronics from April 26-29, 2011. This course will cover specimen preparation and materials analysis techniques applicable to electronic assemblies, components, and devices. The course consists of classroom instruction, demonstrations, and hands-on laboratory training.

Lecture topics will include physics-of-failure-based root cause analysis, guidelines for selection of analytical tools, and practical instruction on laboratory techniques. The laboratory portion of the course includes demonstrations and step-by-step sample preparation using metallographic techniques on the latest failure analysis equipment from Buehler. In addition, a number of important non-destructive and destructive analysis techniques will be demonstrated, including:

1. **Failure analysis techniques**
   - ***Non-destructive analysis techniques***
   - • Destructive analysis
   - • Sample extraction, package decapsulation
   - • Mounting and micro-sectioning
   - • Grinding, polishing, etching
   - • Metallography
   - ***Inspection and materials characterization***
   - • Failure analysis techniques
   - • X-ray inspection, Computed Tomography (CT)
   - • Scanning Acoustic Microscopy (SAM)
   - • Environmental Scanning Electron Microscopy(ESEM)
   - • Energy Dispersive Spectroscopy (EDS)
   - • X-ray Flouroscence (XRF) Spectroscopy
   - • Other analytical techniques
2. **Failure mechanisms of electronic products**
3. **Root cause analysis**
4. **Physics of failure**

Engaging and knowledgeable lecturers from CALCE and Buehler will provide practical recommendations based on pertinent case studies. Each course attendee is invited to submit one sample to CALCE at least three weeks before the course starts. Several of the submitted samples will be prepared and analyzed, in advance, for use during course demonstrations. Other samples will also be used for hands-on training sessions during the course to illustrate specimen preparation procedures and analysis techniques. For more information and registration, please visit **www.calce.umd.edu/facourse/** or contact Bhanu Sood at bpsood@calce.umd.edu.

Han to Lead Warpage/Coplanarity Course at 2011 IPC APEX EXPO

Prof. Bongtae Han

Professor Bongtae Han will lead an IPC Professional Development course titled "Warpage/Coplanarity Measurement During the Assembly Process: Applicability and Limitations of Existing Methods and Future Challenges" at the 2011 IPC APEX EXPO on April 10, 2011. Han, director of the CALCE Laboratory for Optomechanics and Micro/nano Semiconductor/ Photonics Systems, will address the application of warpage/coplanarity measurement, the limitations of existing measurement methods, and potential challenges with the process in this course.

Han will also review all existing warpage/coplanarity measurement techniques that have been implemented for packaging applications, with selected results from each technique being presented to illustrate advantages and limitations. Technical challenges associated with future package and substrate developments and advanced methodology developments will also be discussed. For more information on this Warpage/Coplanarity course, please contact Professor Han at bthan@calce.umd.edu.

Han, Research Group Prove Value of Barrier Coating in Flexible Electronics

Professor Bongtae Han and his research group have published three papers documenting their work on barrier coatings used in flexible electronics in high-profile physics journals—including *Applied Physics Letters*, *Journal of Applied Physics,* and the *Journal of Chemical Physics*—since 2008. Culminating years of dedicated research and experimentation, each paper is expected to greatly impact standards for the application of barrier coating in flexible electronics manufacturing.

Below is a list of the most recent papers published by the Han research group:

1. **Analytical and Molecular Simulation Study of Water Condensation Behavior in Mesopores with Closed Ends**, C. Jang and B. Han, *The Journal of Chemical Physics*, Vol. 132, 104702, 2010.
2. **Analytical Solutions of Gas Transport Problems in Inorganic/Organic Hybrid Barrier Structures**, C. Jang and B. Han, *Journal of Applied Physics*, 105, 093532, 2009.
3. **Ideal Laminate Theory for Water Transport Analysis of Inorganic/ Organic Multilayer Barrier Films**, C. Jang, Y. Cho and B. Han, *Applied Physics Letters*, Vol. 93, 13307, 2008.

CALCE Presents at 2010 IMECE

CALCE was a major presence at the 2010 International Mechanical Engineering Congress & Exposition (IMECE) of the American Society of Mechanical Engineers (ASME). Professor Abhijit Dasgupta lead a group of CALCE students and investigators in presenting the latest CALCE research during the 6-day event, held at the Vancouver Convention and Exposition Center in Vancouver, British Columbia, Canada, from November 12-18, 2010.

Dasgupta and his research group presented their research and review posters during the three-day technical program at the heart of the exposition, addressing the latest findings in physics-of-failure (PoF) qualification, modified Iosipescu specimen evaluation, SAC305 fatigue durability, crack initiation and propagation in wavy solder IMC interfaces, multi-Scale modeling of Pb-free solder interconnects, and much more.

The IMECE is one of the ASME's premier annual events, bringing together professional and student engineers from an assortment of mechanical engineering disciplines to showcase research, discover new testing and measurement methodologies, and establish professional and research partnerships. For more information on Professor Dasgupta and his research group's attendance at IMECE, please contact him at dasgupta@calce.umd.edu.

CALCE Contributes to Development of Revolutionary LED Bulb by GE

NISKAYUNA, New York, Oct 21, 2010 (BUSINESS WIRE) — Scientists from GE Global Research—the technology development arm of the General Electric Company—GE Lighting, and the University of Maryland—as part of a two-year solid-state lighting program with the U.S. Department of Energy—have announced the successful demonstration of a 1,500-lumen LED bulb (a standard 100-watt halogen PAR38 bulb produces 1,500 lumens) that addresses key barriers to the widespread adoption of LED bulbs for general lighting.

The prototype provides a snapshot of the future: "The scientists and technology leaders involved in this collaboration are dissolving some major barriers to the commercialization of general lighting LED bulbs," says John Strainic, global product general manager for GE Lighting. "We're taking swings at issues such as higher light output options, thermal management, and bulb size and weight. This kicks open the door to the solid-state age that is upon us." This LED technology achievement was announced during a future of lighting symposium that GE hosted at its Global Research headquarters in Niskayuna, NY.

As part of the DOE project, GE and the research team of Professors Bongtae Han and Avram Bar-Cohen at the University of Maryland's A. James Clark School of Engineering have developed and demonstrated novel cooling technologies that effectively manage the heat and promote lower system costs by reducing the number of LED chips required when compared to conventional cooling technologies.

Mehmet Arik, a mechanical engineer at GE Global Research and principal investigator on the LED project, says, "This is a revolutionary cooling technology with great promise. It has the potential to help us take LED lighting performance and efficiency to new heights. Through further research and improvements, we may be able to increase performance without compromising the efficiency or lifetime of an LED bulb."

Aviation and Energy Roots

GE's cooling solution is based on technology the company now uses in its aviation and energy businesses. GE Global Research has a world-class team of fluidics experts who specialize in technologies that manage flow. They are developing innovative ways to control airflow and combustion to dramatically reduce the amount of pressure losses and loading characteristics in aircraft engines and power generation in gas and wind turbines.

Arik adds, "Just one floor down in the same research building, I have colleagues using our dual cool jets technology to improve both the power and efficiency of GE's jet engines and power generation turbines. With wind turbines, for example, we're manipulating airflow to increase wind energy production. With LEDs, we're using dual cool jets to improve the heat transfer rate and reduce the number of chips in the lamp."

How GE's Dual Cool Jets Technology Works

GE dual cool jets are very small micro-fluidic bellows-type devices that provide high-velocity jets of air, which impinge on the LED heat sink. These jets of air increase the heat transfer rate to more than ten times that of natural convection. The improved cooling enables LED operation at high drive currents without losses in efficiency or lifetime. For a given lumen output, the dual cool jets' improved thermal management reduces the necessary LED chip count. This, in turn, can dramatically lower the cost of the lamp. In addition to performance and cost advantages, this cooling technology enables reductions in LED lamp size and weight.

GE and the University of Maryland are in the final stages of the DOE project. The organizations are now studying ways to improve the reliability and lifetime of LED lighting systems. For more information on this project, please contact Professor Han at bthan@calce.umd.edu.

Source: GE Global Research

CALCE Developing Solution for Determining EOR

In collaboration with Harris Corporation and the FAA, CALCE is developing a method for calculating the effective end-of-repair (EOR) date on systems composed of multiple assemblies where each assembly is composed of multiple parts and parts may appear within more than one assembly. EOR is defined as the last date the system can be supported. The methodology will use data from a FRACAS (Failure Reporting and Corrective Action System), the state of existing parts inventories, the obsolescence status of the individual parts, and part obsolescence forecasts. The objective of the resulting analysis is to provide the capability to continuously generate an EOR metric that can be used to monitor the sustainability of a system.

As part of a Diminishing Manufacturing Sources and Material Shortages (DMSMS) plan for a system, parts are routinely monitored for life cycle status and availability using internally performed supplier monitoring and/or external commercial database services. When a part is identified as being high risk or obsolete, a DMSMS case or record is created to capture this life cycle information. Processes may then be initiated to mitigate the impact of the part's diminished life cycle status on the systems that depend on the part. One possible mitigation process could consist of an assessment of the component's failure history, evaluation of the current inventory of the part, and an estimation of the inventory required to sustain the support process for assemblies that contain the part for a specified period of time. If the current inventory is determined to be insufficient, then additional parts can be procured if they are available. For systems in sustainment mode, the primary impact on the system due to part unavailability is the inability to repair failed assemblies, which may result in a reduced capability to support the operational system. If a customer plans to operate the system until a specific point in the future, the EOR date for each assembly within the system becomes an important parameter to monitor. The solution to this problem is complicated by the fact that many parts are used within multiple assemblies in a system and/or have poorly defined failure histories. Additional complications include part loss in inventory, replacement of non-failed parts during repair, inventory from salvaged assemblies, demand for parts associated with planned upgrades to the system, and multiple inventories. Adding to these complications is the possibility that the sustainability of selected assemblies within a system could be "sacrificed" in order to extend the EOR for the rest of the system.

CALCE is developing a stochastic discrete-event-simulation solution that allows the determination of assembly-specific EOR dates for a system. The discrete-event-simulator can model the demand associated with every instance of a part in every assembly within a system and include assembly-specific (and globally available) part inventories to determine system EOR dates. Uncertainties in failure dates are modeled using a Monte Carlo analysis approach that results in distributions of EOR for systems, i.e., an EOR with an associated confidence level can be obtained. The model is being applied to the analysis of the Voice Switching and Control System (VSCS) supported by Harris Corporation for the FAA. Contact Peter Sandborn (sandborn@calce.umd.edu; 301-405-3167) at CALCE for more information on this project.

CALCE Presents, Leads Workshops at ISTFA 2010

CALCE investigators shared their latest research on counterfeit part detection and mitigation at the 36th International Symposium for Testing and Failure Analysis (ISTFA). CALCE investigators presented a paper on diode failure analysis, "Methodology for Analysis of Schottky Diode Failures," and led tutorials on Counterfeit Electronics Detection and Mitigation Strategies during the event, sponsored by the ASM Electronic Device Failure Analysis Society (EDFAS). EDFAS fosters education and communication in the failure analysis community while championing technology advancement and improved the performance and reliability of devices and materials for the electronic industry. ISTFA provides attendees with an opportunity to acquire the latest knowledge from leading professionals in failure analysis with six days of tutorials, short courses, technical presentations, panels, and user groups. The exposition also features leading edge instruments and solutions targeted towards industry. For more information on CALCE participation at ISTFA, please contact Bhanu Sood at bpsood@calce.umd.edu.

CALCE Expands with New MEMS Group

CALCE celebrated the founding of its newest group, the MEMS Group (MEMSG), with a informative and lively kickoff meeting last summer. Welcoming a number of attendees from the electronics industry and research communities, the MEMS Group introduced its unique mission to an enthusiastic audience. Established in early 2010 by Dr. Ravi Doraiswami, the CALCE MEMS Group will expand the center's focus beyond electronics reliability, failure analysis, and prognostics.

The MEMS Group will offer solutions to industry-level issues with micro-electro mechanical components and systems, and address challenges in healthcare, energy harvesting, and prognostics and health management (PHM). The group will also explore new approaches to predict system failure and extend its expertise to investigating the reliability of bio-medical instruments and developing BioMEMS sensors for healthcare applications; researching wireless networking and the uses of remote monitoring in studying systems during field operations; and developing guidelines and standards for RF MEMS, BioMEMS, and microfluidic MEMS reliability. To learn more, visit the MEMS Group website at www.calce.umd.edu/MEMS/ or contact Ravi Doraiswami at ravidsw@calce.umd.edu.

CALCE-CityU Exchange Program Prepares Tomorrow's Research Professionals Today

The Center for Advanced Life Cycle Engineering (CALCE) welcomes interns from City University of Hong Kong each year through an ongoing exchange program between the University of Maryland and City University. Interns from City University participate in research on a number of the center's industry-sponsored projects in the areas of electronics products and systems reliability. Now in its sixth year, the exchange program has garnered superb results and broadened the avenues of research collaboration between City University and CALCE.

Four interns from City University—Jiaqi Song, Jixiang Chen, Yu Feng Zhou and Jie Chuai—worked with CALCE last summer. The visiting interns assisted CALCE investigators, including CALCE Test Services and Failure Analysis Laboratory Director Bhanu Sood, on work with major FY11 projects, including Thermal Management Trends in LED Lighting Systems, FMMEA Analysis of Laptop Computers, and Tin Whisker Growth. After a month of work, the interns presented their midterm progress to Prof. Anthony Fong, Associate Professor and Director of the EDA Centre at City University's Department of Electronics Engineering in July 2010. The exceptional work of the City University interns and Prof. Fong's positive reception of their midterm progress reveals the continued excellence produced by the CALCE-City University Intern Exchange Program. For more information on the CALCE-City University Intern Exchange Program, please contact Diganta Das at digudas@calce.umd.edu.

Indian E-Waste Legislation Adds Material Restrictions

The Government of India's Ministry of Environment and Forests proposed new e-waste policies to reduce hazardous waste and ensure the environmentally sound disposal of electrical waste and electronic equipment in May 2010. Similar in many ways to the European Union's Waste in Electronic and Electrical Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) regulations, the proposed policies address the production-to-disposal life cycle of electronic equipment and include detailed instructions on handling electronic waste.

The proposed e-waste policies provide direction on threshold limits and disposal procedures for four heavy metals—lead, mercury, cadmium, and hexavalent chromium—and sixteen (16) additional substances, including: copper beryllium alloys, tetrabromobisphenol-A (TBBPA), and liquid crystals. For some materials, a threshold limit has not been specified, and, in its current form, the policy document does not clearly state the measurement technique to be used for assessing content level, nor has it identified any exempt materials. For more information on India's new e-waste policies, please contact Michael Osterman at osterman@calce.umd.edu.

Dasgupta, Research Group Win Best Paper Award

Professor Abhijit Dasgupta, Research Associate Moustafa Al-Bassyiouni and Ph.D. candidate Cholmin Choi were selected as winners of the 2010 R.A. Evans and P.K. McElroy Best Paper Award at the 2010 Reliability and Maintainability Symposium (RAMS) for their paper "Improved Reliability Testing with Multiaxial Electrodynamics Vibration." Developed in collaboration with United States Army Materiel Systems Analysis Activity (AMSAA) members Ed Habtour and Gary Drake, the paper addresses reliability concerns with next-generation, electronics-rich DoD platforms—such as Small Unmanned Ground Vehicles (SUGV) and Small Unmanned Arial Vehicles (SUAV)—and the combined efforts of CALCE and AMSAA to provide cost-effective solutions to these challenges through vibration testing with a novel six-degrees-of-freedom shaker.

The Evans/McElroy Best Paper Award is presented for technical papers presented at the annual Reliability and Maintainability Symposium that demonstrate superior comprehension of technical material and offer positive contributions to the fields of reliability and maintainability. Sponsored by IEEE and AIAA, the annual Reliability and Maintainability Symposium is one of the nation's premier reliability, availability, and maintainability engineering events. RAMS combines tutorials, presentations, CEUs, certifications, and networking into one week-long program, delivering the most current information and state-of-the-art research to representatives from a range of technical industries. For more information of Professor Dasgupta's award-winning paper and his work with AMSAA, please contact him at dasgupta@calce.umd.edu.

Choi Wins Second Student Presenter Award

Cholmin Choi

For the second time in a year, CALCE Ph.D. candidate Cholmin Choi won the Best Student Presenter Award for his presentation of his research on vibration interconnect reliability of HVQFN assemblies. Cholmin was selected best student presenter for his presentation "Physics-of-Failure (PoF) Qualification of Complex Electronic Systems" by over 40 members of the CALCE Electronic Products and System Consortium (EPSC) at the EPSC Fall Technical Review. Cholmin's presentation, the result of his work with Professor Abhijit Dasgupta, addressed PoF-based qualification of HVQFN assemblies used in electronic systems under different types of vibration excitation.

The Best Student Presenter Award was presented to Cholmin, a doctoral candidate in Mechanical Engineering at the Clark School of Engineering, by departing Industrial Advisory Board Chairman Mike Davisson of Agilent. For more information, please contact Professor Abhijit Dasgupta at dasgupta@calce.umd.edu.

CALCE to Lead PHM Session at ICVRAM 2011

Date: April 11-13, 2011; Venue: College Park, Maryland, USA

The International Conference on Vulnerability and Risk Analysis and Management (ICVRAM) will be held on April 11-13, 2011, at the Marriott Inn & Conference Center, College Park, MD, USA. The objective of ICVRAM2011 is to provide a forum for experts and decision makers involved in vulnerability and risk analysis and management to share information on current and emerging hazards and research results affecting specific applications.

The Conference General Chair is Prof. Bilal Ayub from the Civil Engineering Department of the A. James Clark School of Engineering at the University of Maryland. Prof. Ayub is also a member of the CALCE PHM Group, which is organizing a session on Prognostics and System Health Management under the Integrative Risk Management topic for this conference. Registration opened in December 2010. For more information on how to participate in the conference, please visit the conference website, **www.asce.org/instfound/cdrm/icvram/**, or contact Professor Bilal Ayub at ba@umd.edu or Sony Mathew at sonym@calce.umd.edu.

CALCE Develops PHM Tutorial for COMADEM 2011

Date: May 30 - June 1, 2011;Venue: Stavanger, Norway

The 24th International Congress on Condition Monitoring and Diagnostics Engineering Management will be held in Stavanger, Norway. The congress will cover all aspects of performance monitoring, health management, failure diagnosis, risk, reliability, maintenance, prognostics, and more.

COMADEM 2011 organizers have arranged for social events and tours during and after the conference for attendees to experience Norwegian culture and the panoramic natural surroundings. CALCE is supporting this conference and organizing a special session on Prognostics and System Health Management. For details, visit www.comadem2011.org or contact Nikhil Lakhkar at nlakhkar@calce.umd.edu.

Selected Publications

The CALCE Publication Archive offers a complete collection of journal and conference papers published by CALCE faculty and students. The archive is updated daily and abstracts from posted publications are available to all public visitors. CALCE consortia members may view the full text of publications with an active web or articles access account. Below is a list of recent additions to the archive:

1. **A Probabilistic Description Scheme for Rotating Machinery Health Evaluation,** Q. Miao, D. Wang and M. Pecht, *Journal of Mechanical Science and Technology*, Vol. 24, No. 12, pp. 2421-2430, 2010.
2. **Modeling Approaches for Prognostics and Health Management of Electronics,** S. Kumar and M. Pecht, *International Journal of Performability Engineering*, Vol. 6, No. 5, pp. 467-476, September 2010.
3. **Failure Precursors for Polymer Resettable Fuses**, S. Cheng, K. Tom, and M. Pecht, *IEEE Transactions on Devices and Materials Reliability*, Vol.10, Issue.3, pp.374-380, 2010.
4. **Computer Manufacturing Management Integrating Lean Six Sigma and Prognostic Health Management**, G. Niu, D. Lau, and M. Pecht, *International Journal of Performability Engineering*, Vol. 6, No. 5, pp. 453-466, September 2010.
5. **Prognostics of Interconnect Degradation Using RF Impedance Monitoring and Sequential Probability Ratio Test**, D. Kwon, M. Azarian, and M. Pecht, *International Journal of Performability Engineering*, Vol. 6, No. 5, pp. 443-452, September 2010.
6. **Application of Grey Prediction Model for Failure Prognostics of Electronics**, J. Gu, N. Vichare, B. Ayyub, and M. Pecht, *International Journal of Performability Engineering*, Vol. 6, No. 5, pp. 435-442, September 2010.
7. **Approach to Fault Identification for Electronic Products Using Mahalanobis Distance**, S. Kumar, T.W.S. Chow, and M. Pecht, *IEEE Transactions on Instrumentation and Measurement*, Vol. 59, No. 8, pp. 2055-2064, August 2010.
8. **A Prognostics and Health Management Roadmap for Information and Electronics-Rich Systems**, M. Pecht, *IEICE Fundamentals Review*, Vol. 3, No. 4, pp. 25-32, 2010.
9. **Effectiveness of Embedded Capacitors in Reducing the Number of Surface Mount Capacitors for Decoupling Applications**, M. Alam, M. Azarian, M. Osterman, and M. Pecht, *Circuit World*, Vol. 36, No. 1, pp. 22-30, 2010.
10. **Analytical and Molecular Simulation Study of Water Condensation Behavior in Mesopores with Closed Ends**, C. Jang and B. Han, *The Journal of Chemical Physics*, Vol. 132, 104702, 2010.
11. **China as Hegemon of the Global Electronics Industry: How It Got That Way and Why It Won't Change**, Michael Pecht and Leonard Zuga, *IEEE Transactions on Components and Packaging Technology*, Vol. 32, No. 4, pp. 935-939, 2009.

For complete list of publications, please visit: **www.calce.umd.edu/articles/.**

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