FALL / WINTER 2005

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COMPUTER-AIDED LIFE CYCLE ENGINEERING (CALCE)
ELECTRONIC PRODUCTS AND SYSTEMS CENTER
DEPARTMENT OF MECHANICAL ENGINEERING
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Mission Statement

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

CALCE Receives High Marks from Navy BMP

The BMP Center of Excellence has released a Navy report on the CALCE EPSC best practices. All of the practices exemplified in the report have been recognized as among the best in industry and government. The report places very high marks on the Center's

Parts Selection and Management Process – CALCE EPSC's methodology helps companies of all sizes implement effective parts selection and management procedures. Using the methodology, an organization need not conduct expensive on-site audits, and can avoid warranty and/or product recall problems that commonly result from selection of sub-par parts.

Root-Cause Analysis – CALCE EPSC provides industry with three unique capabilities that mark its root-cause analysis methodology as an industry leader: a holistic approach based on physics of failure (probable causes are linked to sound scientific principles); a systematic and documented process for directing the actual failure analysis investigation; and well-equipped facilities and a highly skilled staff. Combined, these capabilities create a greater likelihood that the actual root cause of a problem is isolated and resolved.

Electronic Parts Obsolescence Forecasting – Electronic part obsolescence forecasting plays a crucial role in managing system obsolescence and life-cycle costs. Current tools are prescriptive and have significant limits when it comes to predicting future part obsolescence. CALCE EPSC's methodology is more accurate in this regard. This is a huge step toward enabling proactive life-cycle planning.

High-Temperature Electronics Design for Reliability Methodologies and Software – CALCE EPSC has developed design for reliability methodologies and software tools that guide the environmental characterization, component testing, materials selection, package architecture determination, and reliability assessment of electronic products and systems for high-temperature electronic applications. The result enables the timely development of competitive, cost-effective, high-temperature electronic products and systems.

Manufacturing Cost Modeling – In today's competitive environment, all cost impacts associated with assemblies must be understood to properly assess the assemblies' market value. This is as true in low-volume avionics applications as it is in the retail electronics field. Engineers are now expected to participate in determining the economic tradeoff for their design decisions. CALCE EPSC develops application-specific models that facilitate the tradeoff analyses required in the electronic substrate manufacturing and electronic assembly businesses. The Center's approach is unique because of its ability to make application-specific and application-independent models targeting electronic substrate and electronic assembly manufacturing. This results in modeling techniques that target conditions of interest to determine if a new technology, material, or process will be cost competitive with existing ones.

The final survey report detailing the findings is available on the Best Manufacturing Practices (BMP) program web site at: *http://www.bmpcoe.org/bestpractices/internal/calce/index.html*.

New CALCE Consortium Members

- Argon ST, Fairfax, VA
- Tessera, San Jose, CA
- Arbitron, Columbia, MD
- GCAS, San Marcos, CA

CALCE Technical Review Meeting

The Technical Review Meeting of the CALCE Electronic Products and Systems Consortium has been scheduled for **October 18-20, 2005,** in the Grand Ballroom at the Adele H. Stamp Student Union, on the University of Maryland College Park campus.

All current members of the Consortium are invited to attend. Organizations interested in becoming CALCE Consortium members and wishing to attend the meeting should contact Joan Lee at *joanyuan@calce.umd.edu*. The fee for non-members is $1,500. The agenda for this event is available at *www.calce.umd.edu* under *Upcoming Events*.

The following projects will be presented at the meeting:

- Effects of Manufacturing Variables on Quality and Durability of Lead-free Solder Joints
- Accelerated Qualification of SAC Assembly: Combined Temperature Cycling and Vibration
- Durability of Lead-free Electronic Interconnects under Impact Loading
- Reliability of SnAgCu Solder for High-temperature/High-power Assemblies
- Experiments to Validate calcePWA Vibration Model for Pb/Sn and Sn/Ag/Cu
- Virtual Qualification of Lead-free Power Electronics
- Effect of Temperature Cycle on the Durability of Lead-free Interconnects Sn/Ag/Cu and Sn/Ag
- Durability of Reworked Lead-free and Mixed Lead-free/SnPb Solder Interconnects
- Tin Whisker Risk Metric and Mitigation Strategies for Electronic Assemblies
- Characterization of Moisture Absorption and Desorption for FBGA Packages in Storage and Lead-free Reflow Soldering Conditions
- Robustness of Ceramic Capacitors Assembled with Lead-free Solder
- Reliable Large-area Lead-free Interconnects for Photovoltaic Cells
- Reliability of MCMs under Combined Mechanical and Thermal Stresses
- Failure Mechanisms and Reliability Assessment for Solid-state Lighting Products
- Dynamic Behavior of Plastics under Impact Loading
- Failure Risk Assessment of LCD Modules under Shock and Drop Load Conditions
- Reliability Assessment of Electronic Assemblies under High-G Artillery Launch Load
- Repetitive Shock Events - Experiments and calcePWA Model Development
- Degradation of BME Capacitors in Harsh Environments
- Hermeticity of Wafer-level Package Phase II
- Development of PoF-based Virtual Qualification Methodology for COF Packages Phase III
- Identification of Failure Mechanisms Relevant to Stacked Die Components
- Environmental and Electrical Load Effects on the Electrical Performance of High-density Sockets
- Performance and Reliability Assessment of Commercially Available RF Components in Space Applications
- Study of Ion Migration and Corrosion Resistance on Ultra-thin Pd Pre-plated Film PPF Leadframes
- Failure Assessment of Tape Carrier Package TCP on Plasma Display Panel PDPs
- Effect of Thermal Cycling Conditions on Reliability of Fine-pitch Flip Chip on Flex
- Remaining Life Assessment of Electronic Hardware
- Integrated Health and Usage Monitoring System
- Quantitative Assessment of Uncertainties in Health Monitoring of Electronics
- Lifetime Buy Forecasting
- Decision Support for PHM - Meeting Prognostic Requirements
- Coupling Technology Insertion to Integrated Refresh Costing and Planning
- Heat Sink Fouling in Air-Cooled PCs
- Advanced Liquid Cooled Module for Cooling of High-flux Electronics
- Impact of Temperature on Performance and Lifetime of Plasma Panels using Natural Graphite-based Heat Spreaders
- Influence of Air Flow Arrangement on the Performance of Heat Sinks
- Single-phase Spot Cooling of High-flux Electronics
- Modeling Enhancements to calcePWA: Heat Sinks/Vibration Failure Assessment
- Package and Device Level Failure Assessment Software

Long-term Lead-free Reliability Study Meeting

To extend the knowledge base related to long-term reliability issues introduced by lead-free electronics, CALCE EPSC has initiated a collaborative research study that involves the design, manufacture, and testing of printed wiring assemblies with the objective of obtaining critical missing information related to the long-term (>10 year) reliability of lead-free assemblies.

On Monday, **October 17, 2005**, CALCE EPSC will hold a one-day session on the status of the long-term lead-free reliability program for participants. The purpose of this meeting is to provide a review of findings obtained so far. The meeting will be held in 2164 Martin Hall, on the University of Maryland College Park campus. The review topics include:

- Program overview
- Vibration combined loading test
- Temperature cycling test results
- Electrochemical migration test results
- Microstructure of solder joints
- Tin pest results
- Current status and future experiments

For more information, please go to *www.calce.umd.edu* and click on *Upcoming Events*, or contact Dr. Sanka Ganesan at *sganesan@calce.umd.edu*, tel. 301-405-0765.

Virtual Qualification Software Workshop

Over the past 15 years, the CALCE Electronic Products and Systems Center has developed software to assist engineers in evaluating, designing, and testing electronic hardware. The software provides an integrated design environment that incorporates reliability assessment and life-cycle costing tasks into the earliest stages of the design process. It produces designs that result in cost-effective and reliable electronic components, PWBs, and systems, and enables design and reliability engineers to implement physics-of–failure principles.

On **October 17, 2005**, the CALCE EPSC will be offering a one-day workshop with hands-on training on the use of the current calcePWA and calceFAST software and a discussion of real-world applications, online resources, and future directions.

For more information on the workshop, go to *www.calce.umd.edu* and click on *Upcoming Events* or contact Dr. Michael Osterman at *osterman@calce.umd.edu*, tel. 301-405-8023.

CALCE Offers Assistance for Six Sigma Implementation

The CALCE EPSC is able to offer implementation of Six Sigma principles in your organization. We offer customized courses for upper management as Champions to get the organization motivated and prepared for transition. We offer full training – tests, classes, homework, and project support and consultation. Our courses are offered in self-contained modules. We also have programs designed for training groups of individuals to attain Green Belt and Black Belt status.

For more information contact Dr. Diganta Das 301-405-7770, *diganta@umd.edu* or Prof. David Bigio 301-405-5258, *dbigio@umd.edu*.

CALCE and Wroclaw University of Technology High-Performance Data Acquisition System Vibration Testing of PCBs

In order to assess the long-term reliability of lead-free assemblies, the CALCE Electronic Products and Systems Center initiated a research effort supported by many companies engaged in aerospace, industrial, telecommunications, and oil exploration businesses. As part of this effort, printed circuit board assemblies were built with commercial variations in pad finish and component finish metallurgies. The reliability tests involved subjecting the assemblies to accelerated temperature cycling, vibration, and combined temperature cycling and vibration conditions.

In accelerated vibration tests, which are high-cycle fatigue tests, the cycle duration is on the order of milliseconds. In vibration tests, solder joints are subjected to out-of-plane vibrations, which lead to displacements in the joints in the out-of-plane direction (tensile mode as opposed to shear mode in the temperature cycling). The partial cracks or micro-cracks in solder joints and the degradation of solder joint strength due to intermetallic morphology and thickness can influence the reliability of assemblies subjected to vibrations. These effects can manifest as changes in solder joint resistance. In order to determine how these affect the time-to-failure in vibration tests, all the electrical circuits in a test assembly must be monitored during each vibration cycle.

As commercially available data acquisition systems (such as event detectors and data loggers) could neither satisfy the temporal measurement needs during each vibration cycle nor provide efficient data storage management, CALCE in collaboration with Wroclaw University of Technology, Poland, has developed, demonstrated, and fabricated such a system. The system has the following features:

- 128 channels
- Resistance measurement by 4-point probe (Kelvin) method; range = 0.1 Ohm to 100 kOhm
- Detection window: minimum resistance pulse ~63 ns, average of 4 measurements within each detection window to maximize signal-to-noise ratio
- Digitally controlled current sources
- Resistance threshold and event windows are user defined
- The input data rate is 3 GB/s, while the volume of data sent to the computer system is as low as 100 KB/s. Data storage requirement per day ~10GB
- Data can be converted and saved as a TXT, CSV or XML file; thus it is possible to process with almost any type of data analysis software
- Upgradeable due to FPGA implementation

For further details, please contact Dr. Sanka Ganesan at 301-405-0765, email *sganesan@calce.umd.edu*.

CALCE Research on Tin Pest in Pb-free Solders

Tin pest (also called tin plague) occurs when the tin undergoes allotropic transformation from the ß-tin (with body-centered tetragonal crystal structure) to the α-tin (with diamond cubic crystal structure). The transformation has been reported for temperatures <13°C. This transformation is accompanied by a 26 percent increase in volume. This volumetric strain in a solder joint can have a potentially deleterious effect on its lifetime. Moreover, the tin pest is also brittle and weak, which in turn can result in joint failures. Most of the Pb-free alloys that are being implemented are essentially Sn-rich alloys with dilute additions of silver, copper, antimony, and/or bismuth. Thus tin pest could potentially be an issue in applications where solder joints are exposed to low temperatures (<13°C) for long durations. Nucleation of tin pest as well as the temperature can be promoted by heterogeneous nucleation sites including defects and impurities.

The main questions that are currently being addressed by CALCE are whether tin pest occurs, once it occurs how to characterize it, and lastly, the reliability impact of tin pest. CALCE has been conducting experiments to study tin pest in bulk solder samples and solder joints. The key parameters being studied are solder alloy metallurgy, ambient temperature, and surface defects. CALCE has been utilizing optical/SEM microscopy and X-ray diffraction methods to characterize tin pest formation.

For further information, contact Dr. Sanka Ganesan at 301-405-0765, email *sganesan@calce.umd.edu*.

Reliability Assessment of Connectors

Critical to the reliable performance of a connector is that it remain "electrically transparent" during its service life. However, during application, the contact resistance of a connector may increase as a result of normal contact force reduction, contamination, and/or corrosion at the contact interface, and may eventually cause a failure. Knowledge of relationships between contact resistance and the degradation of contact force and interface conditions throughout the life of a connector or contact is therefore required for all reliable contact designs.

CALCE has developed an automated contact resistance probe that provides vibration-free contact normal force and can measure contact resistance as a function of contact force. With the use of this system and in combination with dynamic mechanical analyzer, mixed flowing gas chamber, and other environmental test equipment, CALCE has conducted various studies to analyze, characterize, and model a variety of separable connector constructions to determine their failure mechanisms, the rate at which damage is introduced into the connected systems, and lifetimes. As an example of this research, CALCE has successfully investigated the corrosion of precious-metal-plated contacts, aging and fretting corrosion of lead-free solder alloy coated contacts, stress relaxation of IC sockets under various temperatures, and the contact behaviors of carbon fiber composite contacts. The knowledge gained from these studies will facilitate the development of the connector reliability assessment function to be integrated into the calcePWA software.

For further information, contact Dr. Ji Wu, Prof. Michael Pecht or Dr. Michael Osterman at 301-405-5323.

CALCE Offers Organizational Support for Green Electronics Implementation

RoHS–restriction of the use of certain hazardous substances––in electrical and electronic equipment covers the restriction of the use of four metals and two flame retardants in electronic products sold in Europe beginning July 1, 2006. An organization's strategy (i.e., business, legal, and technical policies) to comply with the RoHS regulation should be established both at the corporate and the division levels, and documented in the form of a position statement that is distributed to customers and suppliers. The position statements will be industry-specific and the contents will depend on the requirements of the supply chain. To meet these needs, CALCE can help your organization develop an appropriate position paper that conveys the information to your supply chain correctly.

Many companies are currently in the process of determining if their products will be RoHS-compliant, based on their current bills of materials. Companies whose bills of materials (and databases) are not up to date with current part numbers, manufacturers, date codes, lot traceability, and mapping of internal part numbers to manufacturer part numbers will find RoHS compliance difficult, expensive and time consuming. Appropriate logistic changes must also be made in the procurement of parts--for example, letting a contract manufacturer or distributor pick an alternative form, fit, or function-equivalent part, since such a part is not necessarily RoHS compliant. CALCE can assist your organization in bill of material evaluation for RoHS compliance.

For more information, contact Dr. Diganta Das 301-405-7770, *diganta@umd.edu* or Dr. Valérie Eveloy 301-405-5280, *veveloy@calce.umd.edu*.

EM China–CALCE Partnership in China

EM China (Electronics Manufacturing China), published by Reed Electronics Group, is the authoritative technical publication for China's fast-growing electronics manufacturing industry. Launched in November 2002, it is read by over 15,000 engineers and managers responsible for recommending, buying, and specifying products and technologies used in semiconductor and electronics manufacturing.

EM China is publishing a CALCE article (in Chinese) in each issue to share the experience and electronic reliability methodologies developed by CALCE with peers in China. *EM China* is also reporting those CALCE activities that are related to China or are beneficial to the Chinese electronics industry. *EM China* covers electronics manufacturing, packaging, surface mount technology, printed circuit boards, and related test and measurement equipment technology. It offers an integrated information service that combines the resources in the bi-monthly print version, website (*www.emchinamag.com*), and four e-newsletters. The magazine keeps manufacturing engineering professionals and managers in China abreast of the latest and most appropriate technologies, industry news, and viewpoints of both leading technology vendors and industry specialists.

For further information, please contact Dr. Ji Wu at 301-405-5901, email *jwu@calce.umd.edu*.

Health and Usage Monitoring of Electronics

Commonly-used electronics reliability prediction methods generally do not accurately account for the life-cycle environment of electronic equipment. This arises from either fundamental flaws in the reliability assessment methodologies used or uncertainties in the product life-cycle loads. Although the use of appropriate stress and damage models permits a more accurate account of their physics-of-failure, their application to long-term reliability prediction based on extrapolated short-term life-testing data or field data is typically constrained by insufficient knowledge of the actual application environment of the product.

CALCE recently undertook a case study in health and usage monitoring of electronics for a commercial notebook computer. The objective was to demonstrate a method of environmental and usage data collection that can enable health monitoring of electronics. This study was part of ongoing efforts at the Center to develop and implement health monitoring methodologies in next-generation electronic equipment. While a comprehensive health monitoring plan may involve multiple life-cycle conditions, such as humidity, vibration, shock, radiation, and contamination, the study focused on temperature measurement. Notebook internal temperatures were dynamically monitored in situ during all phases of the life cycle, including usage, storage, and transportation. The data collected were analyzed statistically using data simplification and cycle-counting algorithms, and converted into a format that can be used in physics-of-failure model, for both damage estimation and remaining life prediction due to specific failure mechanisms.

The effects of power cycles, usage history, CPU computing resources usage, and external thermal environment on peak transient thermal loads were characterized. The CPU heat sink temperature was found to be 13°C and 8°C lower than its maximum rating over 90 percent and 95 percent of the monitored time period, respectively. This highlights the potential conservativeness of thermal management solutions optimized for worst-case operating conditions that rarely occur. Such findings could contribute to the design of more sustainable, least-energy-consumption thermal management solutions.

About 97 percent of the temperature cycles experienced by either the CPU heat sink or hard disk drive had an amplitude of less than 5°C. However, the maximum temperature cycle amplitudes measured were found to exceed those specified by environmental standards for computer and consumer equipment. Such a discrepancy between standardized and actual conditions provides a strong motivation for monitoring actual product application environments.

The monitored life-cycle temperature data could be applied in a life-consumption monitoring methodology such as the one developed by CALCE to provide both damage estimation and remaining life prediction due to specific failure mechanisms influenced by temperature. The measured data could also be used to determine the stress levels to be imposed in accelerated testing, refining product specifications, and setting product warranties.

For further information, please contact Dr. Peter Rodgers at 301-405-8126, *rodgers@calce.umd.edu* or Prof. Michael Pecht at 301-405-5323, *pecht@calce.umd.edu*.

Cardiovascular Disease Monitoring

Cardiovascular disease (CVD) is the leading cause of death in many regions worldwide, accounting for nearly one-third of global deaths. When considered as either a primary or contributing cause, CVD mortality represents nearly 60 percent of all mortality in the United States. The aging of the population in developed countries will result in an increased incidence of CVDs, which also represents the second largest cause of death in the U.S. population aged less than 15.

CVDs are chronic diseases, or wearout mechanisms, from a reliability engineering viewpoint. The majority of cardiac deaths are sudden deaths that occur before the patient can reach a medical care facility. Although current medical and clinical approaches of CVD assessment, such as ultrasonic and magnetic resonance imaging (MRI), can provide direct and accurate evidence of heart disease, these techniques only provide periodic (intermittent) assessment of the disease. There is a need for continuous CVD monitoring to enable the timely detection of precursor symptoms to sudden death, and to enable the long-term management of chronic conditions through monitoring of symptoms, risk factors, and regimen compliance.

Among commercially available cardiovascular (CV) monitors, electrocardiogram (ECG) monitors and implantable pacemakers and cardioverter defibrillators are considered the most mature technologies. These devices address arrythmia diagnosis, surveillance, and treatment, but there is a need for systems capable of monitoring other critical CV conditions leading to sudden or premature death through accurate sensing of critical physiological parameters.

CALCE's goal is to develop ambulatory cardiovascular monitoring solutions using electrical and mechanical sensing technologies to measure physiological and activity parameters indicative of cardiovascular function such as ECG, blood pressure and velocity, oximetry, bioimpedance, and cardiac sounds. The monitoring methodologies investigated for integration into ambulatory monitors are analogous to those developed at the Center for electronics health monitoring. The challenges that must be overcome to successfully apply current concepts to CVD diagnosis and follow-up include:

- compactness for integration of biomedical sensors, diagnosis, treatment, and wireless data transmission into one system
- timely, accurate, and reliable decision algorithms that prompt action for real-time data interpretation of cardiovascular catastrophesor off-line data interpretation for disease surveillance
- low power consumption
- data storage, transmission, and security
- motion and other measurement disturbance rejection
- ergonomics for wearable devices and biocompatibility for invasive devices
- reliability
- minimal or zero maintenance

It is intended that the CV monitors could complement traditional medical and clinical care to help reduce CVD mortality and cost, and to improve the follow-up of CVD patients.

For further information on these initiatives, contact Dr. Valérie Eveloy at 301-405-5280, email *veveloy@calce.umd.edu* or Prof. Michael Pecht at 301-405-5323, email *pecht@calce.umd.edu*.

CALCE Studying Role of PCB Assembly Materials on Electrochemical Migration

A failure mode of ongoing concern to the electronics industry involves current leakage due to a reduction in surface insulation resistance (SIR) between adjacent conductors on the surface of printed circuit boards (PCBs). One mechanism for this failure is known to be electrochemical migration (ECM), which is the growth of conductive metal filaments, typically dendrites, on a PCB through an electrolytic solution under the influence of a DC voltage bias. This process can result in intermittent or permanent electrical failures of the PCB. An intermittent failure can occur once or repeatedly, and is particularly difficult to diagnose. Intermittents are experienced when the leakage current density rises and eventually exceeds the current-carrying ability of the dendrite, causing it to fuse open. Susceptibility to ECM thus has a direct impact on the functionality of electronic systems, especially within high-humidity and high-temperature environments.

Recent developments in PCB assembly materials and processes may have unanticipated effects on failure rates due to ECM. These changes include the elimination of post-reflow PCB cleaning and the introduction of lead-free materials for RoHS compliance. CALCE is actively studying the impact of these changes in materials and processes, as well as continued reduction in conductor spacings, on the risk of failure due to electrochemical migration.

In an effort to reduce costs and facilitate processing of higher density assemblies with fine-pitch and low-profile components, the electronics industry has begun adopting no-clean solder technology. This change has been enabled by the introduction of low-residue solder fluxes. However, the long-term effects of no-clean flux chemistries on PCB assemblies in the electronics industry are largely unexplored. One of the conclusions from CALCE's work in this area is that temperature-humidity-bias (THB) conditions specified in some industry standards for SIR testing of electronic assemblies may not be suitable for evaluation of PCBs processed with no-clean technology. Another outcome of CALCE's research is that the absence of a post-solder cleaning step increases the risk of ECM failures due to PCB contamination by non-conductive foreign matter, such as fibers. Although such contamination does not pose a direct risk of electrical shorting, the enhanced moisture absorption and potential ionic content of fibrous contaminants can accelerate path formation in the ECM process, leading to premature failure.

The transition by the electronics industry to lead-free materials also brings with it uncertainties with regard to the risks of ECM. The effort to comply with restrictions on the use of lead and other hazardous materials has resulted in the introduction of new materials for solder, PCB substrates, component and solder pad platings, and solder fluxes, as well as higher reflow temperatures. CALCE is currently conducting a comparative study on electrochemical migration that includes assemblies using tin-silver-copper (SAC), tin-silver solder alloys, and eutectic Sn-Pb solder. CALCE's current and future research in this area also addresses ongoing reductions in conductor pitch, which reduce migration distances and hinder the ability to effectively clean areas under components and connectors.

For further information on this work, please contact Dr. Michael H. Azarian at 301-405-5280, email *mazarian@calce.umd.edu*, or Prof. Michael Pecht at 301-405-5323, email *pecht@calce.umd.edu*.

CALCE Develops an Integrated Modeling Scheme for Combined Hygroscopic and Thermomechanical Stresses

Moisture plays an important role in the integrity and reliability of plastic encapsulated microelectronics (PEMs). The moisture in the plastic packaging reduces interfacial adhesion strength and produces hygroscopic stresses through swelling mismatches. The previous research at CALCE revealed that the moisture-induced deformation can be as large as the deformation induced by temperature change in some plastic packages.

In environments such as automotive and telecommunications applications, where packages are subjected to both temperature excursion and relative humidity change, the hygroscopic swelling mismatch must be considered together with thermal expansion mismatch deformations for accurate reliability assessment. Accelerated life testing conditions such these inside as a HAST (Highly Accelerated Stress Test) chamber, where temperature, humidity, and pressure are used, also witness the complications produced by combined hygroscopic and thermo-mechanical issues.

Numerous studies using finite element analysis have been conducted to determine thermomechanical or hygroscopic stresses. However, no rigorous attempt to develop non-linear stress analysis capabilities for combined hygroscopic and thermomechanical stresses has yet been reported. In a recent study (C04-35), CALCE, in collaboration with engineers at Samsung Techwin (CALCE Consortium member), developed a nonlinear stress analysis scheme to analyze the combined effect of thermal and hygroscopic deformation. Figure 1 depicts a hierarchy of the combined stress analysis. It is basically a combination of heat transfer, moisture diffusion, and static stress analyses, which allows the systematic coupling of three different deformation fields.

The sequence of the combined analysis includes (1) a heat-transfer analysis to calculate the transient temperature field, which will be used as an environmental variable in the next step, (2) a moisture diffusion analysis to provide the moisture contents as a function of time and position, and (3) a stress analysis based on the deformations produced by mechanical loadings as well as thermal and hygroscopic loadings.

It is important to note that the proposed combined analysis allows use of the nonlinear constitutive equation of the materials, such as viscoelasticity or creep. Linear superposition of each strain component can be used to determine the total strain in the linear elastic material, but it is not valid when material nonlinearity is involved.

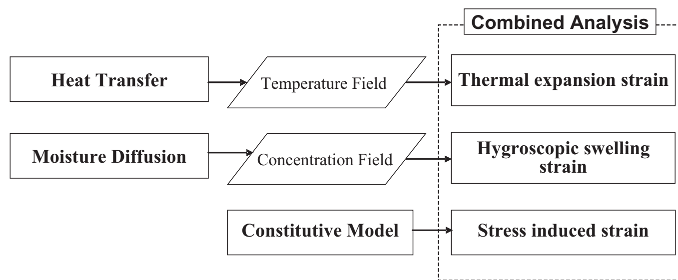

Figure 1. Modeling hierarchy for combined stress analysis

In the scheme, the mass diffusion function available in ABAQUS is employed to obtain the transient diffusion field. The saturated concentration is treated as a temperature-dependent variable using an option in ABAQUS (*FIELD), that enables a user to specify the values of predefined field variables. The temperature field is specified by a separate option (*TEMPERATURE). Using the two options, the temperature and concentration field can be utilized simultaneously for the stress analysis. In addition, the hygroscopic swelling is implemented using a user-defined subroutine of ABAQUS.

The validity of the proposed approach was verified using experimentally determined displacement fields of a bimaterial specimen subjected to a combined thermal and hygroscopic loading. The bimaterial specimen used in the experiment is shown in Figure 2. It consists of NCP (non-conductive paste) and EMC (epoxy mold compound). After pre-baking at 125°C for 48 hours, a specimen grating was replicated on the specimen at 85°C and the specimen was then subjected to 85°C/85%RH. After moisture absorption, the sample was cooled to room temperature; the resulting displacement field due to the temperature change and moisture intake was documented by moiré interferometry. Figure 3 shows the results obtained from the experiment and a visco-elastic FEM analysis. The modeling prediction agrees well with the experimental results.

The new modeling strategy provides a complete solution for real package operating conditions, where transient moisture diffusion, heat transfer, hygroscopic swelling and thermomechanical stress occur simultaneously. The scheme is versatile and can accommodate complex constitutive relationships such as viscoelasticity that are often ignored in the hygroscopic stress analyses of polymeric materials. For more information, contact Dr. Samsoon Yoon at *ssyoon@calce.umd.edu* or Prof. B. T. Han at *bthan@calce.umd.edu*.

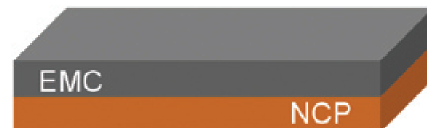

Figure 2. EMC/NCP bi-material joint

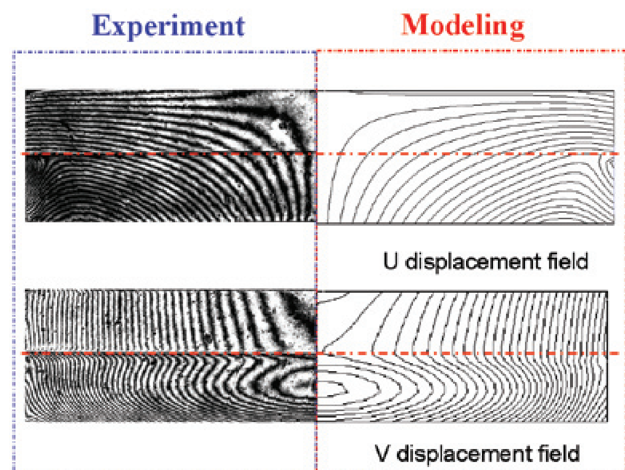

Figure 3. U and V displacement due to combined effect of thermal contraction and moisture induced swelling (Left side: Experiment, Right side: Viscoelastic FEM analysis)

CALCE Wins Best Paper of the Year Award

Eric Stellrecht, Prof. B.T. Han and Prof. Michael Pecht of the CALCE Electronic Products and Systems Center won the Best Paper of the Year award for the article "Characterization of Hygroscopic Swelling Behavior of Mold Compounds and Plastic Packages," published in the *IEEE Transactions on Components and Packaging Technologies*. The paper was selected from among all the manuscripts published in 2004 by this journal, which included many outstanding international papers.

The authors received the award at the *55th Electronic Components and Packaging Technology Conference (ECTC)* in Orlando, Florida, on June 2, 2005. The award includes $2500 cash prize (shared by the authors) and a certificate for each author.

CALCE Quality System Certified to ISO 9001:2000

The British Standards Institute recently certified CALCE's quality system to the requirements of the new ISO 9001:2000 standard, Quality Management Systems - Requirements. The audit, which resulted in the certification of the quality system, was performed first as part of a triennial process associated with both the 1994 and 2000 versions of the standard, and second to verify that the policies and procedures of the quality system had been revised and augmented to reflect the new requirements of the standard. These changes required that the quality system and its policies and procedures be process-driven and more customer-oriented, apply greater application of quality objectives and quality planning, and be subject to continuous improvement. The new standard replaced the 1994 versions of ISO 9001, 9002, and 9003, and became the newest member of the ISO 9000 family of specifications.

Perhaps of all the changes made to the 1994 version of the specification, the most important is concerned with the requirement that organizations "continually improve the effectiveness of the management system through the use of the quality policy, quality objectives, audit results, analysis of data, corrective and preventive actions, and management reviews." This requirement imposes on CALCE management the responsibility to ensure that problems are identified, analyzed, and corrected in a timely fashion and that policies, procedures, and assignments of authority and responsibility are implemented to prevent the recurrence of problems and to improve the overall effectiveness of the quality system.

For more information, please contact Dr. Keith Rogers at 301-405-5316, *krogers@calce.umd.edu*.

CALCE Ph.D. Candidate Receives SMTA Award

Leila Jannesari, a CALCE Ph.D. candidate working under the supervision of Prof. Abhijit Dasgupta, was recently awarded the 2005 Charles Hutchins Educational Grant from the Surface Mount Technology Association (SMTA) and *Circuits Assembly* magazine for her project titled "The Effect of Voids, Caused by Manufacturing Variation, on the Thermo-mechanical Durability of Lead-free Solders."

This $5000 grant is awarded annually to a graduate-level student pursuing a degree and working on thesis research in electronic assembly, electronics packaging, or a related field. This is the first time a student from the University of Maryland has received this award.

The award will be presented at the *SMTA International Conference* on September 28, 2005, in Donald Stephens Convention Center in Rosemont, Illinois.

Selected Recent CALCE Publications

- **The Impact of Lead-free Legislation Exemptions on the Electronics Industry**, M. Pecht, Y. Fukuda, and S. Rajagopal, *IEEE Transactions on Electronics Packaging Manufacturing*, Vol. 27, No. 4, pp. 221-232, October 2004.
- **New Aging Mechanism in Multilayer Ceramic Capacitators**, D. Donahoe and M. Pecht, *Advanced Packaging,* Vol. 14, No. 16, pp. 16-17, June 2005.
- **The Evaluation of Copper Migration During the Die Attach Curing and Second Wire Bonding Process,** T. Lin, M. Pecht, D. Das, J. Pan, and W. Zhu, *IEEE Transactions on Components and Packaging Technologies*, Vol. 28, Issue 2, pp. 337-344, June 2005.
- **Electromagnetic Interference (EMI) Reduction from Printed Circuit Boards (PCB) Using Electromagnetic Bandgap Structures**, S. Shahparnia and O. Ramahi, *IEEE Transactions on Electromagnetic Compatibility*, Vol. 46, No. 4, pp. 580-587, November 2004.
- **Numerical Heat Transfer Predictive Accuracy for an In-Line Array of Board-Mounted PQFP Components in Free Convection**, V. Eveloy, P. Rodgers, and M.S.J. Hashmi, *Transactions of the ASME, Journal of Electronic Packaging*, Vol. 127, No. 3, pp. 1-10, September 2005.
- **An Investigation into the Potential of Low-Reynolds Number Eddy Viscosity Turbulent Flow Models to Predict Electronic Component Operational Temperature**, P. Rodgers, V. Eveloy, and M.S.J. Hashmi, *Transactions of the ASME, Journal of Electronic Packaging*, Vol. 127, No. 1, pp. 67-75, March 2005
- **An Assessment of Embedded Resistor Trimming and Rework**, P. Sandborn, *IEEE Transactions on Electronics Packaging Manufacturing*, Vol. 28, No. 2, pp. 176-186, April 2005.
- **A Warranty Forecasting Model Based on Piecewise Statistical Distributions and Stochastic Simulation**, A. Kleynor and P. Sandborn, *Reliability Engineering and System Safety*, Vol. 88, No. 3, pp. 207-214, June 2005.
- **Hybrid Experimental and Computational Approach for Rate Dependent Mechanical Properties Using Indentation Techniques**, J. Varghese, G. Radig, D. Herkommer, and A. Dasgupta, *Proceedings of the 6th International Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro-Systems, EuroSimE*, pp. 510-514, April 2005.
- **Characterization of Non-Conductive Adhesives**, D. Farley, A. Dasgupta, J. Caers, and W. Hua, *Proceedings of the 6th International Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro-Systems*, *EuroSimE*, pp. 471-477, April 2005.
- **Forecasting Technology Insertion Concurrent with Design Refresh Planning for COTS-Based Electronic Systems,** P. Singh and P. Sandborn, *Proceedings Reliability and Maintainability Symposium,* pp. 349-354, January 24-27, 2005.
- **A Data Mining Based Approach to Electronic Part Obsolescence Forecasting,** P. Sandborn, F. Mauro, and R. Knox, *Proceedings of DMSMS Conference,* Nashville, TN, April 2005.
- **Development of Predictive Modeling Scheme for Flip-chip on Fine Pitch Flex Substrate,** C. Jang, S. Han, Y. Kim, H. Kim, S. Yoon, S. Cho, C. Han and B. Han, *6th. International Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro-Systems, EuroSimE,* pp. 566-574, April 2005.
- **Extending the Limits of Air-Cooling in Microelectronic Equipment,** P. Rodgers, V. Eveloy, and M. Pecht, *Proceedings of the 6th Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro-Systems, EuroSimE,* Berlin, Germany, pp. 695-702, April 18-20, 2005.
- **Room Temperature Soldering of Microelectronic Components for Enhanced Thermal Performance,** J.S. Subramanian, P. Rodgers, J. Newson, T. Rude, Z. He, E. Besnoin, T.P. Weihs, V. Eveloy, and M.G. Pecht, *Proceedings of the Sixth conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro-Systems, EuroSimE,* Berlin, Germany, pp. 681-686, April 18-20, 2005.
- **Heart Sound Measurement and Analysis in Cardiovascular Disease Assessment, V. Eveloy, Y. Liu,** and M.G. Pecht, *Proceedings of the SMTA Medical Electronics Symposium,* Minneapolis, MN, April 25-27, 2005.

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