Predictive Materials Aging & Reliability
Five Year Plan for FY08-12

Performing Organization: Sandia National Labs
Principal Investigator: Rob Sorensen, 505.944-5558, nrsoren@sandia.gov

Customer	Collaboration
Steve Marotta, US Army Redstone 256-876-9283	***Contact for RRAPIDS. Working to include engineered aging structures in DoD hardware.***
Tom Erickson Tom.erickson@us.army.mil, 256-876-0218 (Redstone)	***Materials in general. TCG lead. Primary contact for adhesives degradation. Primary contact for DoD hardware information.***
Don Skelton, Picatinny (Army Corrosion Office) 973-724-4071	***MEMS & MEMS applications.***
Jim Zunino, Picatinny (Army Corrosion Office), 973-724-6773	***MEMS & MEMS applications.***
Robert Kuper, Picatinny	***Post-Mortem characterization of prospective replacement MEMS devices.***
Abdul Kudiya, Redstone Arsenal (AMRDEC)	
Dave Locker, Redstone Arsenal (AMRDEC)	
Mike Bucher, NSWC	
Michael Deeds, NSWC	

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Ken Adkins ***Kenneth.adkins@us.army.mil*, 918-420-8236** ***ARMY-DAC-McAlester OK***	***Advice on application to Army hardware***
ARDEC, US Army Redstone	***MEMS Device Reliability***
Army Corrosion Office (Picatinny Arsenal)	***MEMS Device Reliability***
Bob Paulson, Sandia, (Enhanced Surveillance)	***Enhanced Surveillance manager.***
Jeff Braithwaite, Sandia, (Enhanced Surveillance)	***Directs materials aging efforts for Enhanced Surveillance. Integrator for SOHPAC.***

Predictive Materials Aging & Reliability Funding

Planned:

FY08	FY09	FY10	FY11	FY12
$862K	$885K	$888K	$890K	$890K

Historical:

prior FYs	FY03	FY04	FY05	FY06	FY07
	$1140K	$1190K	$1056K	$1235K	$760K

Values include the total of both DoD and DOE $s

Predictive Materials Aging & Reliability Funding by Task for FY08

Tasks *	FY08 Funding**	FY07 Funding
1. Solder	$180k	$150K
2. Corrosion	$220k	$187K
3. Adhesives	$252k	$225K
4. MEMS	$210k	$188K
Total FY08 Project Funding	$862k	$760K

*Indicate a new task as “(new start)” next to title
**Indicate any previous-year task that was terminated as $ 0K

Values include the total of both DoD and DOE $s

Predictive Materials Aging & Reliability GOTChA

Goal: Predict the effect of materials aging on system performance (solder, corrosion, adhesives, MEMS)

Objective: Develop physical-based models for key degradation processes.

Challenges:

Solder
- Modeling the mass transport mechanisms of Sn-whiskering
- Developing an assembly process that provides consistent solder joint quality

Corrosion
- Environment (micro & macro unknown)
- Corrosion is controlled by latent defects
- Electrical system model unavailable
- Validation data do not exist

Adhesives
- Measuring hydrolysis in ultrathin (~100 Å) silane films in adhesive joints
- Extrapolating to low temperature, low water content, and a range of pH
- Validating model for a range of silane chemistry

MEMS
- Test structures in surface polysilicon and LIGA only
- Mechanism-properties relationships do not exist
- No link to reliability of MEMS devices
- No mechanism for translating results into DOD/DOE device design.

Predictive Materials Aging & Reliability GOTChA

Approach:

Solder
- Determine the interface microstructure and reaction kinetics
- Identify Sn whisker growth vs. time, temp, and stress

Corrosion
- Use engineered aging structures to monitor corrosion
- Develop corrosion model for known defects and degradation modes
- Generate a device-level failure criterion & model
- Validate with field returned units & dormant storage parts

Adhesives
- Measure degrad. of fract. toughness at high temp. and extrapolate to lower temp. using hydrolysis kinetics from thin film measurements

MEMS
- Start with SOI as MEMS (relevant to DOD/DOE missions)
- Fabricate test structures in 2nd, preferably metal-based, MEMS processing technology
- Use DOD input, previously developed test structures and fundamental knowledge gained from mechanism-properties studies to guide direction of aging and environment studies.

Tasks:

Solder
- Obtain Sn diffusion rate kinetics by creep tests
- Evaluate 3-D package test vehicles

Corrosion
- Complete bondpad model f([Cl], RH, T)
- Develop EAS structures for bondpad & connector corrosion
- Deploy EAS structures with tuned sensitivity in storage locations
- Perform failure analysis on field returns (database)

Adhesives
- Fracture toughness measured at high temp.
- Hydrolysis kinetics in thin films vs temp. and pH for different silanes

MEMS
- Develop key mechanism-properties relationships in SOI
- Develop key mechanism-properties relationships in 2nd processing technology

Solder Interconnect Reliability

Phemenological and Numerical Models for Predicting Reliability

- Assess interface reactions (microstructure and rate kinetics) between Pb-free solders and Pd.
- Develop a computational model to predict Sn whisker growth.
- Investigate 3-D packaging technology for high-reliability applications.

Impact

- Understanding Sn-Ag-Cu/Pd reactions will minimize process defects and reliability concerns of Ni/Pd/Au finishes.
- A Sn whisker growth model will minimize the reliability concerns with COTS parts using 100% Sn finishes.
- A reliability database will enable the implementation of 3-D packaging technology for high-reliability, weapons and space hardware.

Assurance of success

- Sandia has an extensive experience in the study of Pb-free interface reactions.
- Sn whisker model development is a joint effort between Sandia materials and computational engineers and materials scientists at U. of Rochester (NY).
- Contractor (ACI) and Sandia facilities are engaged in the test vehicle evaluation.
- *Partnering with other SNL programs jointly supportng Sn whisker model and 3-D packaging studies.*

Accomplishmens/milestones

- Microstructure and dissolution/IMC rate kinetics of Pb-free solder/Pd interfaces / 09/07.
- Sn whisker data completed for thin film test vehicle/journal article / 09/07
- Set contract with Amer. Compet. Inst. to build 100 3-D packaging test vehicles for reliability analysis / 09/07.

Corrosion

What are you trying to do in this task?

- Produce a validated, physical based model of bondpad & connector corrosion
- Develop engineered aging structures (EAS) to TRL level 7.
- Use EAS deployed in real environments to obtain validation data for the corrosion model.

What makes you think you can do it?

- A first generation model of bondpad corrosion exists.
- Uncertainty quantification techniques are available
- Extensive SNL program on embedded surveillance (electronics, sensor, communication expertise)

What difference will it make?

- The corrosion model will allow us to make reliability predictions based on corrosion in PEM devices and connectors.

What / When Will You Deliver?

- EAS structures for interfacing with RRAPIDS (9/07)
- Second generation corrosion model (11/07)
- Connector corrosion model (11/08)

Adhesives

- **What are you trying to do in this task?**

- **model hydrolysis kinetics of silane films in adhesive joints for conditions experienced in the field**

What makes you think you can do it?

- **We validated a method to measure fracture toughness at high temp.**

- **We developed methods to meas. hydrolysis kinetics in thin silane films for wide range of conditions**

What difference will it make?

- **Hydrolysis of silane coupling agents is a major degradation mechanism in adhesive joints**

- **No kinetic model for hydrolysis of silanes in adhesive joints exists to date that can predict lifetimes for low T and low water content. This model will provide the first such guidance.**

What / When Will You Deliver?

- **Hydrolysis model in the absence of residual stresses (11/07)**

- **Hydrolysis model that includes the effects of residual stresses (9/11)**

MEMS Reliability
Four-Question Chart

What are you trying to do in this task? *Understand the reliability MEMS materials and devices*

- Provide semi-standard measurement techniques, materials and tribological properties data within a MEMS fabrication processes
- Apply results and analysis to lifetime/reliability issues in prospective MEMS devices across the DOD/DOE complex

What makes you think you can do it?

- Previously developed strength, friction and fatigue test designs for SMM polysilicon (one MEMS technology) will guide aging/lifetime/reliability diagnostic studies
- Experience with microsystems reliability physics

What difference will it make?

- Optimized design and reliability of MEMS-based components and systems
- Properties database of MEMS process materials
- Mechanism-based understanding of reliability and lifetime issues associated with MEMS devices

What / When Will You Deliver?

- SOI strength, friction, fatigue test structure fabrication and preliminary evaluation 10/06
- Demonstrated working ability to drop-in any MEMS processing technology by 09/08
- Preliminary lifetime-reliability study using diagnostic test structures 1/08

Solder Interconnect Reliability Key Personnel

Name	Org	Role
Paul Vianco ***ptvianc@sandia.gov*** ***505-844-3429***	***Sandia National Laboratories, Albuquerque, NM***	***Task Leader***
Tom Erickson ***tom.erickson@rdec.redstone.army.mil*** ***256-876-2781***	***US Army RDECOM*** ***Redstone Arsenal, AL***	***Customer***
Professor: Dr. J.C.M. Li ***li@me.rochester.edu*** ***Graduate student: Ms Jing Cheng*** ***jcheng@me.rochester.edu***	***University of Rochester, NY***	***Principle investigators on a portion of the Sn whisker modeling sub-task.***
Jeff Braithwaite ***jwbrait@sandia.gov*** ***505-844-7749***	***Sandia National Laboratories, Albuquerque, NM***	***Enhanced Surveillance Campaign (DoE) providing leveraged support for the Sn whisker modeling sub-task.***
Dan Kral ***djkral@sandia.gov*** ***505-844-4104***	***Sandia National Laboratories, Albuquerque, NM***	***NNSA Satellite Programs (DoE) providing leveraged support for the 3-D package-on-package sub-task***

Corrosion - Key Personnel

Name	Org	Role
Rob Sorensen (nrsoren@sandia.gov – 505.844.5558)	*Sandia*	*Task Leader Atmospheric corrosion*
Jamie Stamps (jfstamp@sandia.gov – 925.294.2132)	*Sandia Livermore*	*Embedded evaluation test bed and hardware*
Steve Marotta (steve.marotta@us.army.mil - 256-876-9283)	*US Army Redstone*	*RRAPIDS point of contact*
David Robinson (drobin@sandia.gov – 505.844.5883)	*Sandia*	*Bayesian techniques, model development*

Adhesives - Key Personnel

Name	Org	Role
Michael Kent ***mskent@sandia.gov, 505-845-8178***	***SNL***	***Task Leader***
Dave Ready ***edreedy@sandia.gov, 505-844-3297***	***SNL***	***Oversee fracture toughness testing***
Doug Adolf ***Dbaolf@sandia.gov, 844-4773***	***SNL***	***Advise on hydrolysis model and other failure mechanisms***
Rob Jensen ***Rjensen@arl.mil, 410-306-1910***	***ARL -Aberdeen***	***Advise on hydrolysis model***
Tom Erickson ***Tom.erickson@us.army.mil, 256-876-0218***	***ARMY-Huntsville***	***Application to Army hardware***
Ken Adkins ***Kenneth.adkins@us.army.mil, 918-420-8236***	***ARMY-DAC-McAlester OK***	***Advise on application to Army hardware***

MEMS Reliability - Key Personnel

Name	Org	Role
Thomas Buchheit *(tebuchh@sandia.gov* *(505)-845-0298*	*Dept. 1824* *Sandia Labs*	*Task Leader*
Michael Dugger *mtdugge@sandia.gov* *(505)-844-1091*	*Dept. 1824* *Sandia Labs*	*Tribology, (Friction, Wear)*
Brad Boyce *blboyce@sandia.gov* *(505)-845-7525*	*Dept. 1824* *Sandia Labs*	*Mechanical Properties*
Danelle Tanner *tannerdm@sandia.gov* *(505)-844-8973*	*Dept. 1769-1* *Sandia Labs*	*Reliability Physics*
Phillip Reu *plreu@sandia.gov* *(505)-284-8913*	*Dept. 1526* *Sandia Labs*	*Applied Mechanics*

Predictive Materials Aging & Reliability Current & Prior FY Results

- Deliverables
  - Peer-reviewed journal article describing the interface reactions between molten SnAgCu solder and Pd (09/07).
  - Peer-reviewed journal article of creep and thin film Sn whisker experiments (09/07).
  - Report on MEMSCap SOI results 2/07
- Milestones
  - Demonstrated corrosion EASs with the embedded evaluation testbed
  - Hydrolysis model in absence of residual stress to be delivered 11/07
- Accomplishments
  - Develop EAS structures for Al bondpad corrosion (1st & 2nd generation)
  - Hydrolysis kinetics partially completed for 3 silane films vs temp. and pH, completed toughness tests for 2 of 3 temps.
  - Designed and developed on-chip SOI fatigue test structures
- Transitions
  - Embedded evaluation workshop held at Redstone (RRAPIDS)
  - RRAPIDS prototype delivered to Sandia and included in dormant storage task
- Other key results
  - Xx

Predictive Materials Aging & Reliability Milestones/Deliverables for FY08-12

Project Milestones/Deliverables ***(What is to be delivered to the customers?)*** ***Suggestion: 1-3 for FY08, and 1-3 for balance of the planning period***			
Milestones/Deliverables	**Date**	**TCG-I & M&SI Taxonomy ID***	**DoD / DOE Linkage**
1. Hydrolysis model in absence of residual stress	***11/07***		***Applicable to all adhesive joints with silane coupling agents***
2. First version of Sn whisker model	***6/08***		***Applicable to all adhesive joints with silane coupling agents***
3. Embedded evaluation EAS devices at TRL 6	***6/09***		***Military systems – long-term storage***
4. Final report on 3-D packaging reliability	***9/09***		***Lighter, smaller weapon systems for the battlefield***
5. Peer reviewed journal article on Sn whisker growth	***9/11***		***All military electronics using COTS components***
6. Hydrolysis model in presence of residual stress	***9/11***		***Applicable to all adhesive joints with silane coupling agents***
7. Demonstrate ability to drop in diagnostic test structures for MEMS processing technology	***FY11***		

Predictive Materials Aging & Reliability
Outcomes/Accomplishments for FY08-12

Task Outcomes /Accomplishments ***(What are the intermediate accomplishments required to achieve project milestones / deliverables?)Suggestion: 1-3 per task***				
Task	**Outcomes/ Accomplishments**	**Date**	**TCG-I & M&SI Taxonomy ID***	**Task Dependencies**
Solder	***Compile data for Sn whisker model*** ***Design & build validation test vehicle for Sn whiskering*** ***Design & build test vehicle for 3-D packaging reliability tests***	***12/07*** ***9/09*** ***9/08***		
Corrosion	***Initial (beta) version of bondpad corrosion model using Bayesian methodologies*** ***Demonstration of EAS structures for Al & Cu corrosion*** ***Deploy EASs in dormant storage***	***11/07*** ***9/07*** ***1/08***		
Adhesives	***Method for studying effect of residual stress on hydrol. Rates*** ***Measure effects of residual stress on hydrol. rate***	***9/08*** ***FY10***		
MEMS	***Report on friction studies on SOI devices*** ***Perform strength, friction, and fatigue reliability studies on 2nd microsystems fabrication technology***	***11/08*** ***11/09***		

Predictive Materials Aging & Reliability Metrics & Exit Criteria for FY08-12

Project Milestone/Deliverable	Metrics or Exit Criteria (Typically 1 per Milestone/Deliverable)
1. Hydrolysis model in absence of residual stress	*Model distributed to DoD* *Journal Article Published*
2. First version of Sn whisker model	*Validated data from laboratory experiments*
3. Peer reviewed journal article on Sn whisker growth	*Article posted on JMP website*
4. Embedded evaluation EAS devices at TRL 6	*Successful use of EAS structures in laboratory test*
5. Final report on 3-D packaging reliability	*Report posted on JMP website*
6. Hydrolysis model in presence of residual stress	*Model distributed to DoD* *Journal Article Published*
7. Demonstrate ability to drop in diagnostic test structures for MEMS processing technology	*Diagnostic test structures and methods successfully employed in two separate technologies*

Predictive Materials Aging & Reliability (Solder)

Solder	FY08	FY09	FY10	FY11	FY12
SnAgCu/Pd Interface Reactions	▲ **Manuscript**				
Sn Whisker Model			▲ **Validated Model**	▲ **Journal Article**	
Compile experimental data	━━━				
Version 1 of model	━━━	━━			
Version 2 of model		━━━	━		
Validation		━━	━		
3-D Packaging Reliability			▲ **Final Report**		
Design & Build relevant test vehicles	━━━				
Perform thermal cycling		━━━			
Failure analysis					
Chip stacking study for 3-D packaging				━━━	━

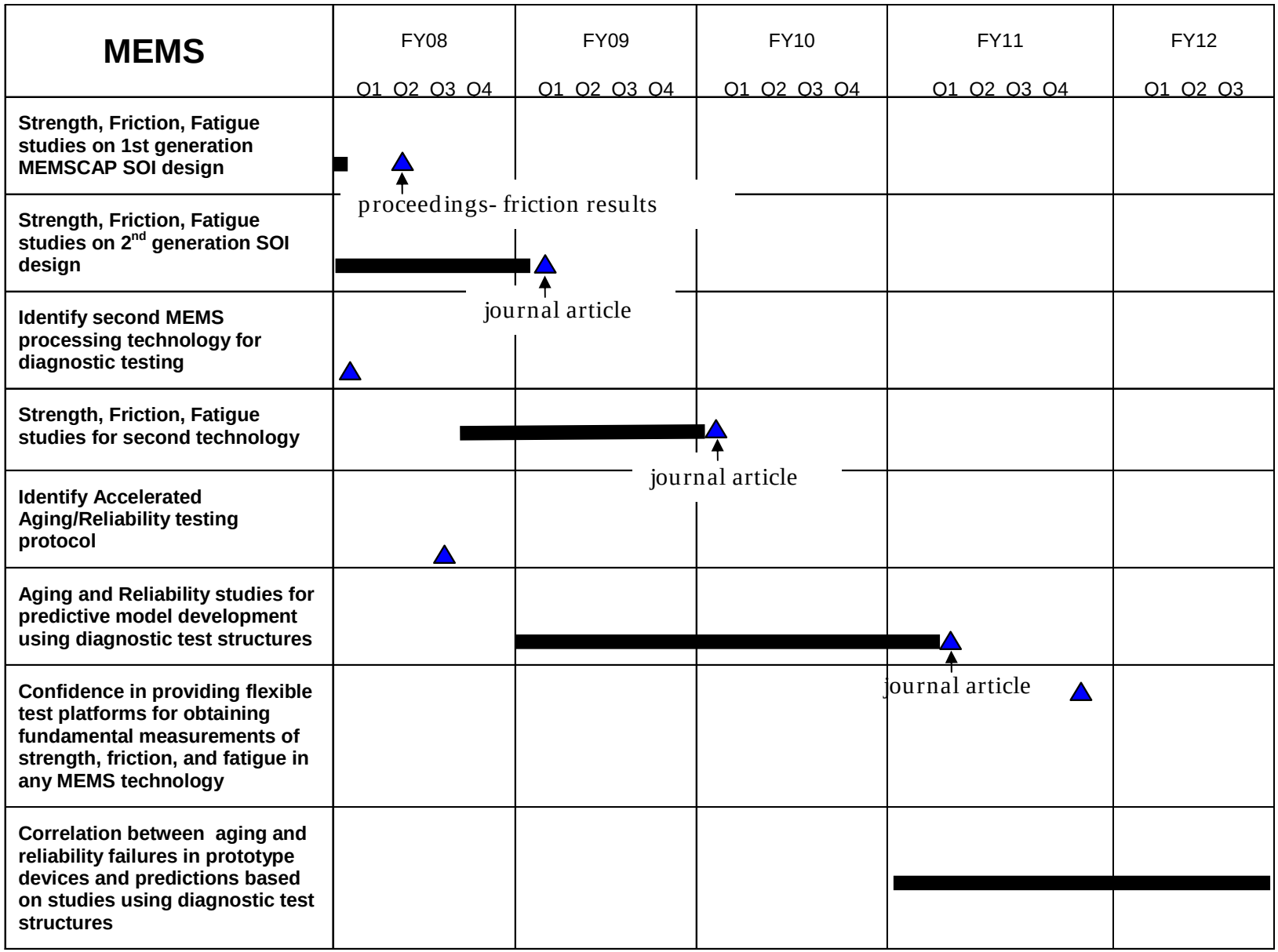
Predictive Materials Aging & Reliability (Corrosion)

Corrosion	FY08	FY09	FY10	FY11	FY12
Bondpad Corrosion Model	**2nd Generation model**	**Journal Article**			**Integrated model**
Link to electrical system					
Connector Corrosion Model		**1st Generation Model**		**2nd Generation Model**	
EAS Structures					
Design and build EAS structures for bondpad & connector corrosion				**TRL 7 level**	
Deploy in dormant storage					
Interface with RRAPIDS	**Initial interface (TRL 5)**				
Use EAS data to exercise model					

Predictive Materials Aging & Reliability (Adhesives)

Adhesives	FY08	FY09	FY10	FY11	FY12
Hydrolysis model in the absence of stress.	▲ Validated Model	▲ Journal Article			
	▬▬▬				
Hydrolysis model that includes residual stress		▬▬▬▬▬▬▬▬▬▬		▲ Validated Model	

Predictive Materials Aging & Reliability (MEMS)



Predictive Materials Aging & Reliability - Issues

Solder

- ***Sn whiskering is not well understood.***
- ***3-D packaging may include processing ideas that affect reliability predictions.***

Corrosion:

- ***Bondpad corrosion is driven by latent defects.***
- ***Al corrosion is stochastic – modeling becomes difficult.***
- ***System performance models are not generally available.***

Adhesives:

- ***Variation of hydrolysis rates for different silane chemistries was not expected and needs to be understood***
- ***Fracture testing to date involves only one silane chemistry. This testing should be performed with a second silane.***

MEMS

- ***MEMSCAP SOI technology contains significant stress in the structural layer***