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Enabling Lead-free in the DoD through Risk Mitigation: Program Management and Systems Engineering Overview

DRAFT Review for Tin Whisker Group Telecon
8/24/2016

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Introduction

- The following slides present some of the details that your team may come across as the lead-free materials are encountered on your program
- The lead-free issues transition throughout the entire product life cycle from concept design through end of life

Land

Sea

Air

Lead-free risk mitigation and team knowledge needed for DoD electronics

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Introduction

What if your repair line discovered Pb-free parts in bins?

Aircraft Control Amp

Ref: http://www.dla.mil/Portals/104/Documents/LandAndMaritime/V/VA/PSMC/Apr14/LM_LeadFreeElectronicsFinishes_151030.pdf

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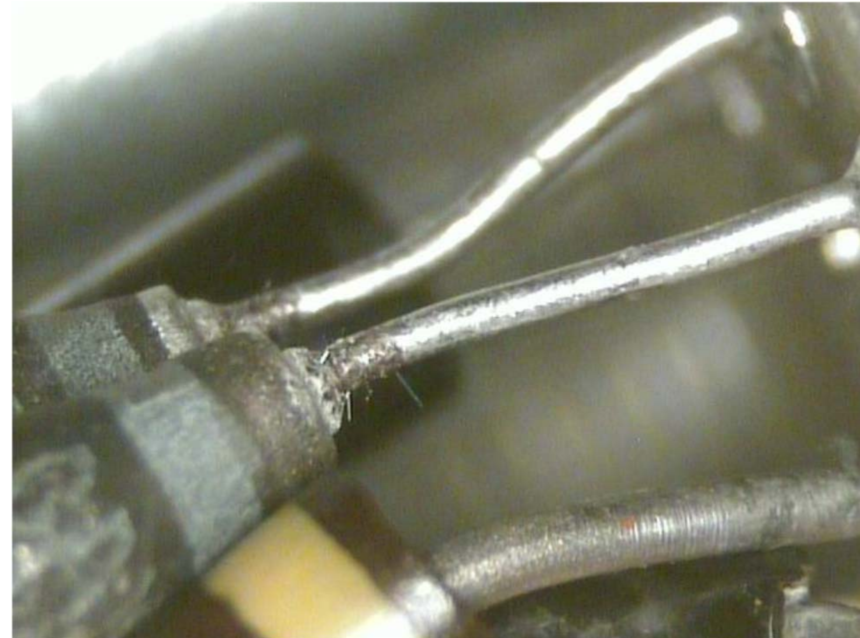
What if your repair line discovered whiskers?



Aircraft Fuel Quantity Indicator

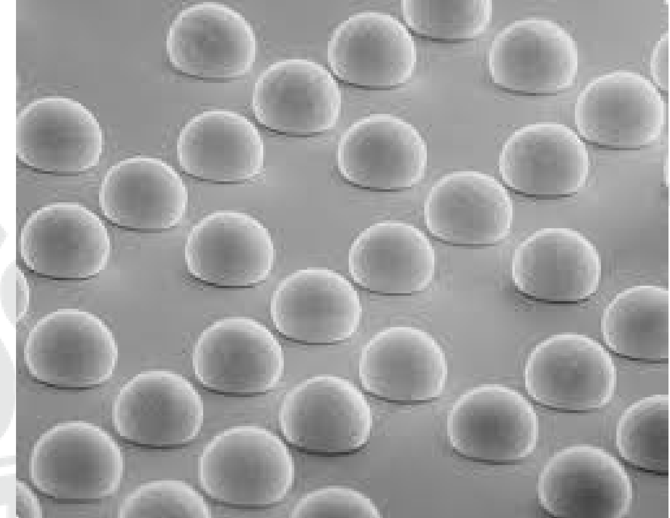
Ref: http://www.dla.mil/Portals/104/Documents/LandAndMaritime/V/VA/PSMC/Apr14/LM_LeadFreeElectronicsFinishes_151030.pdf

Introduction

What if your OEM notified you of a critical part with lead is going end of life?

<u>2012 *IBM* Client communication package</u>

- 200mm **C4 leaded volumes have been declining** over the past five years **due to ROHS** and end-of-life (EOLs) of EFK 9211 Ceramic and HyperBGA substrates
- It is **no longer cost effective for IBM to support this operation** with the small volumes remaining in leaded C4.
- IBM to issue PCNs in September 2012
  - Last Time Buy volumes to be received by 9/1/2013
  - Last Time Ship date ~YE2014
- **EOL extension to 2016** may be possible
  - **Price TBD**



Your program is first:
9 to 24 months of testing to validate new lead-free assembly

End of Life – IBM 200MM Wafer Leaded C4 Bumping

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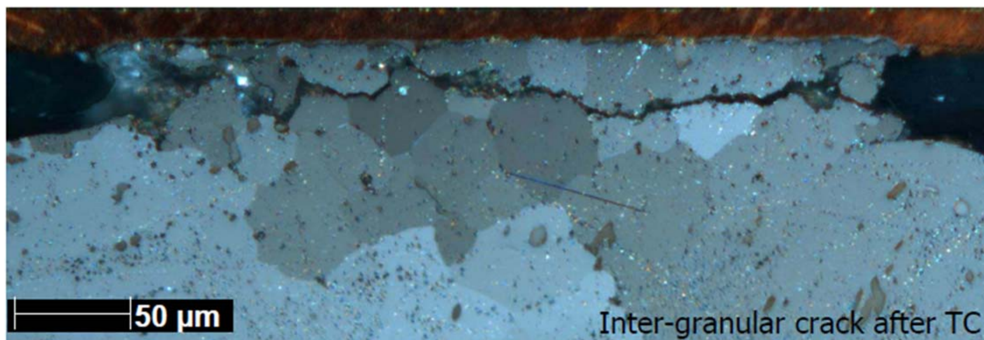
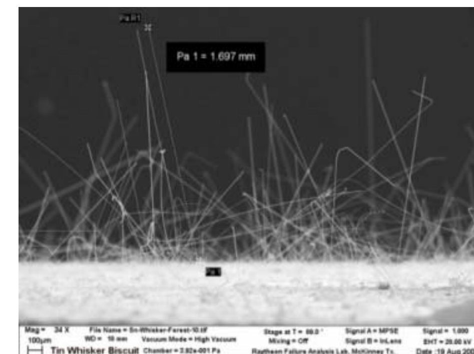
- The **S**trategic **E**nvironmental **R**esearch and **D**evelopment **P**rogram (SERDP) is **DoD's environmental science and technology program**, executed in partnership with DOE and EPA. SERDP invests in basic and applied research and advanced development.
- The **E**nvironmental **S**ecurity **T**echnology **C**ertification **P**rogram (ESTCP) is **DoD's environmental technology demonstration and validation program**. The Program's goal is to identify and demonstrate cost-effective technologies that address DoD's highest priority environmental requirements

SERDP Lead-free Electronics web page



Lead-free solder


Tin whiskers

Mission success depends on reliable electronics

Source: On-line US DoD Systems Engineering,PDUSD-Approved-TDS_AS_Outline-04-20-2011.pdf

Risks:

- ***Push a button and it doesn't go!***
  - ***Broken solder → system fails***
- ***Real-world***
  - ***Unknown armed state in storage***
  - ***Whisker short in the safety switch***

DoD situation:

- ***High Mishap Severity (MIL-STD-882)***
- ***System Failures Unacceptable***

Industry shift to lead-free solder

- *Added failure risk to Mil/Aero electronics*

Biggest concern:

- **Unknown** *lead-free materials used in the wrong place at the wrong time.*

…Impossible without consistent dependable solder connections

Your Regular Everyday Tasks

- Questions:
  - ✓ Does the system have Electrical, Electronic, or Electromagnetic (EEE) components?
  - ✓ Does the system have sub-systems that use EEE components (e.g. pump with an electronic pressure controller) ?
- If yes
  - ✓ Evaluate program reliability, availability, consequences of system failure, etc.
    - ✓ How much reliability is expected by design?
    - ✓ How much reliability can be managed programmatically (hot-swap, spares, etc.)?
  - ✓ **Lead-Free Control Plan (LFCP) for the program becomes critical**
    - ✓ IAW GEIA-STD-0005-1, GEIA-STD-0005-2
    - ✓ Determine tin whisker risk mitigation level. Can lead-free solder be used?
    - ✓ **LFCP requirements flow down** in to subcontractors IAW DI-MGMT-81772
    - ✓ Include in parts, materials, and process systems engineering requirements
      - ✓ Along with other PM&P issues: e.g. counterfeit, obsolescence, corrosion, COTs, etc.
  - ✓ Establish **lead-free team knowledge** for effective control plan review
    - ✓ Programs, Systems, Design, Manufacturing, Repair
  - ✓ Leverage Resources
    - SERDP lead-free risk mitigation research
    - On-going IPC-PERM Council, SAE Documents
    - DoD teams, Industry Consortia, …

PERM = Lead(**P**b)-free **E**lectronics **R**isk **M**anagement

If you don't recognize these items, program is at risk…If you need help, call

Background – DoD Electronics

Unique DoD needs

- Diverse systems
- Harsh environments
- Beyond commercial design practices

COTS = Commercial-off-the-shelf

Global supply chain

- Lead-free COTS electronics
- North America, Asia, Europe
- Small DoD market share

Dual use COTs

- Lead-free electronics
- Low cost
- Available

COTs IR vision system

Go time: Its got to work

Warfighter needs the best capabilities

Without solder, no electronics …. Without electronics, Warfighter has limited: Sight, Senses, Communication, Mobility, Navigation, etc.

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Lead-Free Electronics – Failure Modes & Issues

- **"Tin whiskers" from tin plating and lead-free solder (where it is thin)**
  - Electrical shorts
  - Metal shards, contamination
  - Arc flash leaves metal vapor
- **Environmental Effects**
  - **Fractures** in high shock & vibration environments
  - Higher **melting** temps
- **Configuration control problems**
  - Mixed lead(Pb) and lead-free **inventory**
  - Unidentified component materials
- **Sustainment/Repair**
  - **Incompatibilities** with SnPb Solder
  - **Less-repairable** assemblies

A material alone is not unreliable; The design's use of a material determines reliability

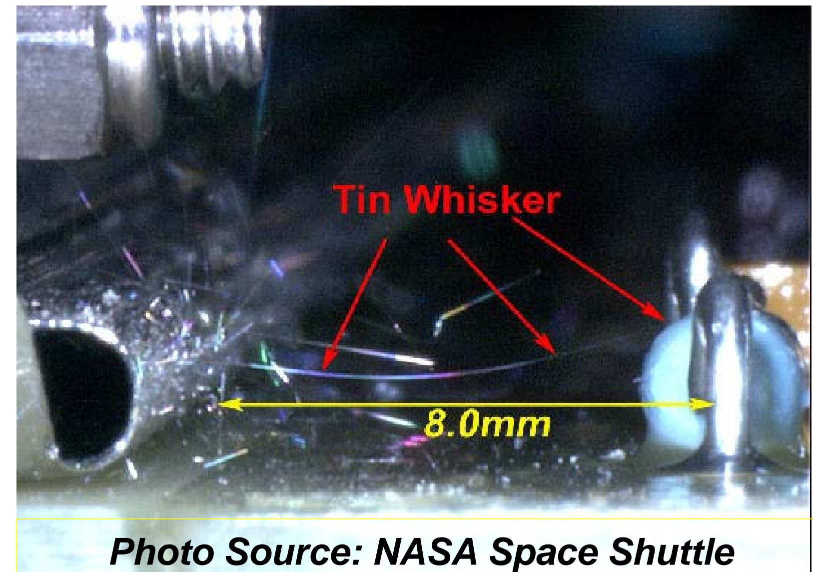

Photo Source: NASA Space Shuttle Program

Electromagnetic Relay Short Circuit

Cracked Solder Joint Open Circuit

Example: Combat Vehicle Electronics

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Lead-free solder impact on manufacturers of electronic products exempt and excluded from RoHS

- Global environmental restrictions on lead increasing
  - Lead-free issues are unavoidable
  - Research started in 1996
  - RoHS implemented **2006** consumer electronics …
  - Medical devices 2016… more to follow
- Tin-lead assembly solder utilizing compatible lead-free parts
  - Components engineering compatibility analysis
- Increased configuration management
  - Materials validation
- DoD/Supplier technical community
  - Working this for many years
  - **Programs unaware of this are at the greatest risk**
- Further loss of traditional and mature electronics
  - Inability to obtain non-RoHS compliant parts
- Greater manufacturing and support challenges for
  - Reprocessed parts (Re-balling and Hot Solder Dip)

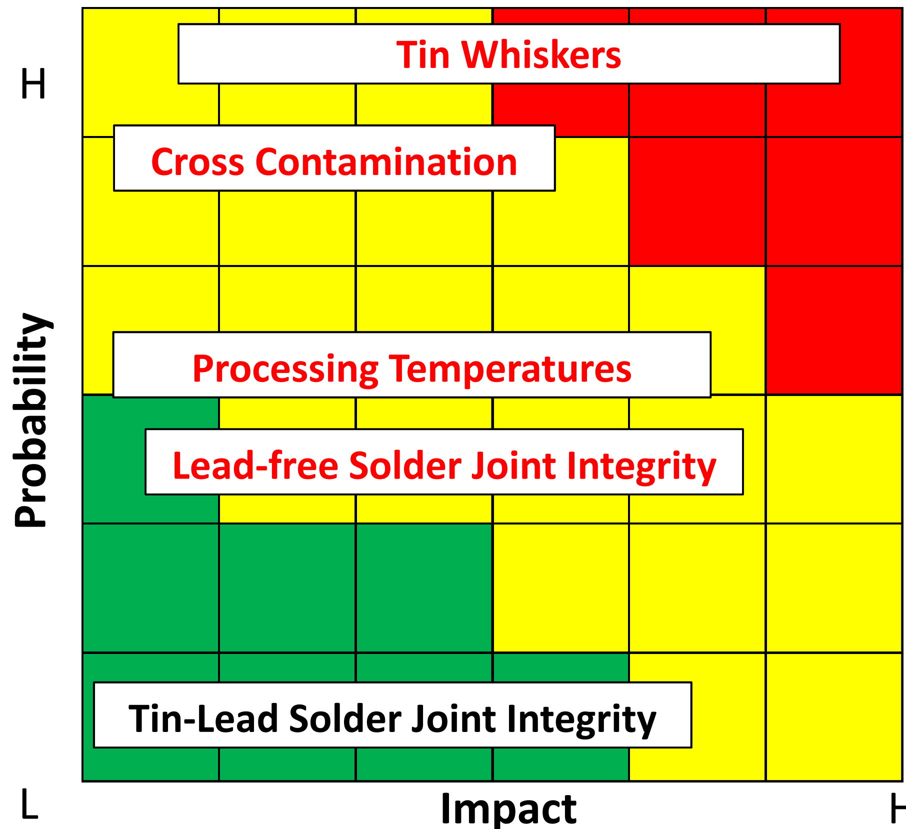
Enhanced vision COTS

Smart munition – long storage

Radar – harsh environment

Escalation of acquisition and sustainment cost due to the major global reduction in the availability of leaded electronics materials

Risk assessment for lead-free materials per DoD Lead Standardization Activity LSA-SOLD-08-07



Frequency of occurrence is **always greater** than the “tin-lead” baseline

Ref: http://www.dla.mil/Portals/104/Documents/LandAndMaritime/V/VA/PSMC/Apr14/LM_LeadFreeElectronicsFinishes_151030.pdf

(Lead not as in Pb but lead as in leader)

Risks and opportunities

	Risks	Opportunities

Heritage tin-lead assembly solder	• **Mitigations to reduce lead-free component's negative system performance impact**
	    • Part reprocessing cost
	• Diminishing COTs sources
	• Loss of technical personnel skill base
	• Lost commercial practices/practitioners
		• Maintain heritage reliability data and design rules
		• Lower tin whisker risk
		    • Tin-lead solder whisker mitigation
		• Tin-lead solder processes available for foreseeable future

Lead-free assembly solder	• **Mitigations to reduce lead-free components and solder negative performance impact**
	    • Vibration/shock mitigation costs
	• **Investment in knowledge:** design rules, manufacturing, reliability analysis/test
	• **Investment in infrastructure equipment:** manufacturing, repair, sustainment, etc.
		• **Leverage commercial materials improvements and practitioners**
		• **Improved sustainment**
		• **Lower long term cost**
		    • Improved parts availability
		    • Reduced parts reprocessing
		• Improved reliability opportunity with next generation lead-free alloys

Either Path	• Tin whisker mitigation • Increased configuration controls • Materials validation testing	• **Proactive response to avoid costly field issues**

Lead-free can work with investment to close DoD systems knowledge gaps

Look in Manhattan project book

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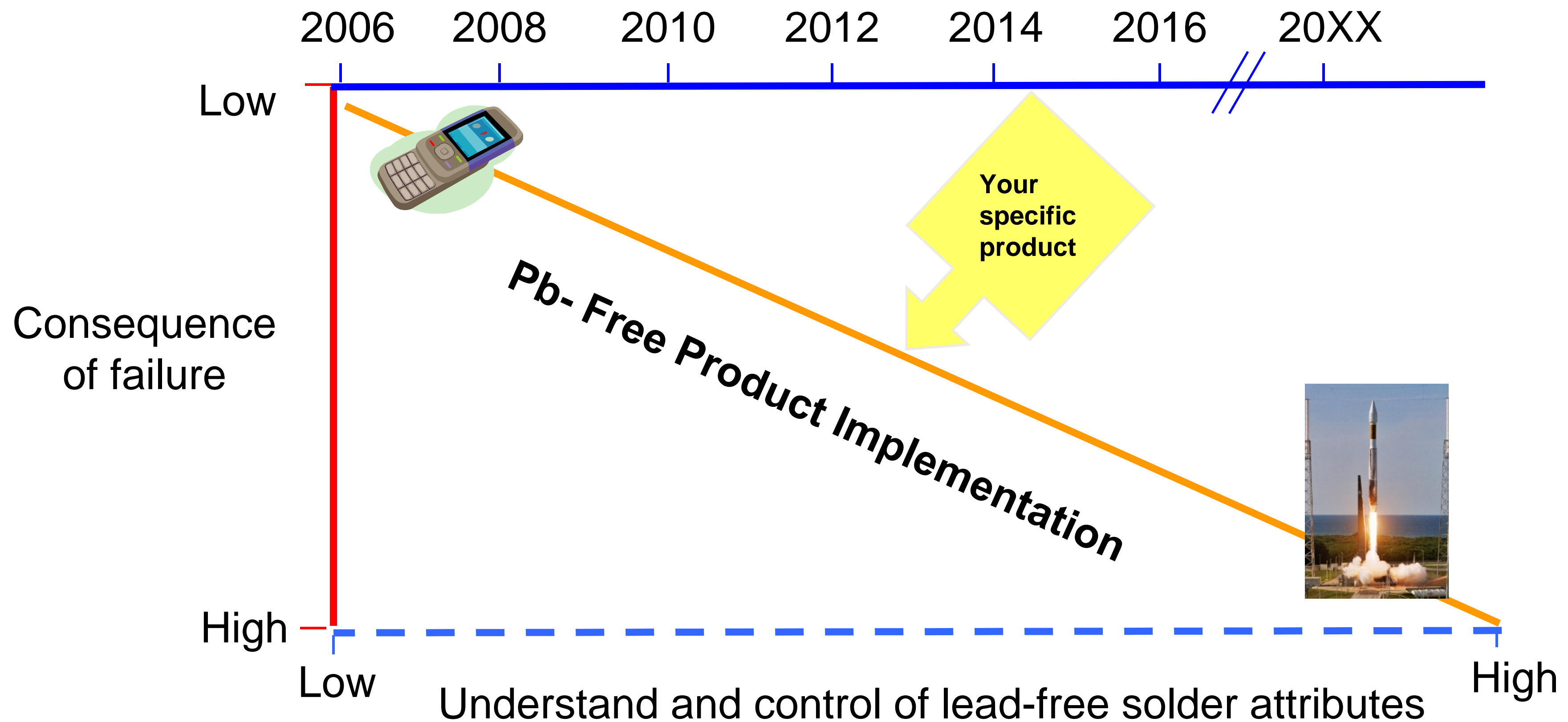
Implementation of lead-free process: Systems Engineering decision



Current status: TODAY

The unknown risk of lead-free content creep can erode design margins and this problem is increasing exponentially, e.g. all military hardware assembled today has some lead-free content

The remaining slides provide examples of things your team must manage effectively in order to ensure program success

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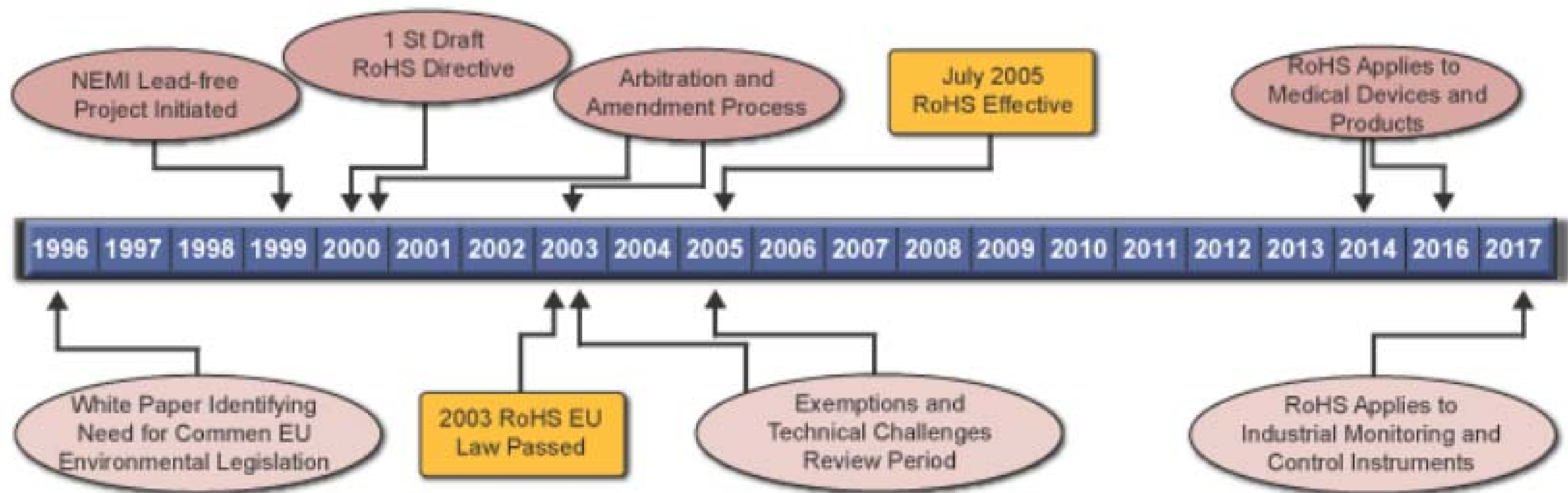
The remaining slides present the back story and details accumulated over the last 10 years by many technical people working to understand the impact of lead-free materials change on DoD and high reliability electronics.

Lead-free electronics initiatives started in 1996 and are evolving to include more equipment



2006 European RoHS Legislation Enforced

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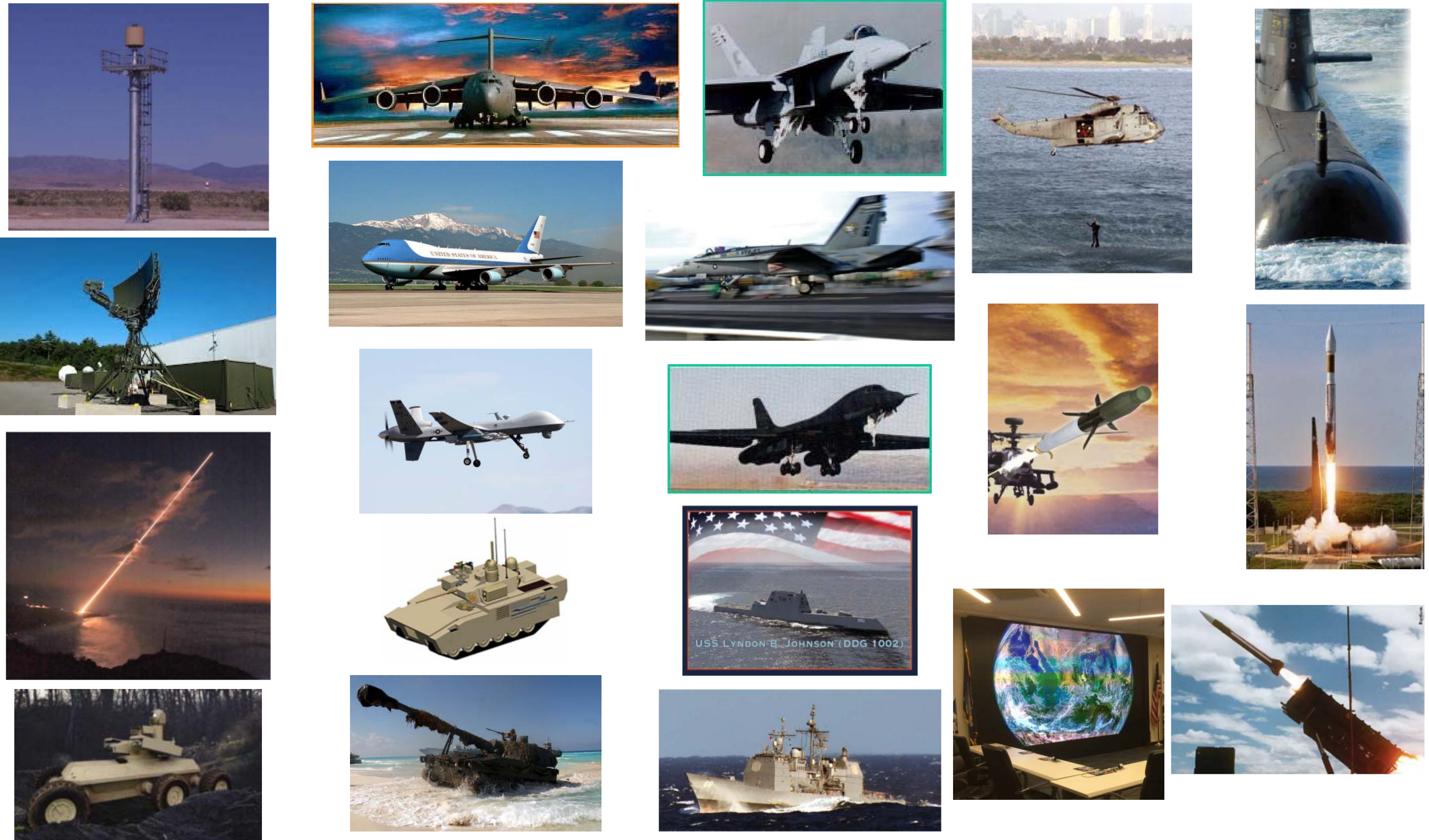
Diverse sets of criticality, equipment, and environments



No one-size fits all solution

Lead-free management tailored to criticality of each systems and subsystem

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Impact: DoD equipment disconnected from main stream soldering processes and materials

- The pool of skilled tin-lead solder practitioners is decreasing
- Majority of published research is associated with lead-free materials
- No money going into tin-lead manufacturing improvements
- Lead-free commercial electronics producers are driving the entire world wide industry

<u>Current real world compatibility issues</u>

Electrical design

"I am working on the tech refresh. This is the only part replacement I found. It has lower cost and overall part count, but it is in a new QFN (quad flat no-lead) package. Will it be reliable?"

Mechanical Design

"This is a tin finished bottom terminated package that has no leads. The only thing I can find on the web is related to lead-free solder. We can use it with tin-lead solder, but need resources to develop the design rules reliability data. We are stuck. Let's meet with programs, systems and manufacturing….

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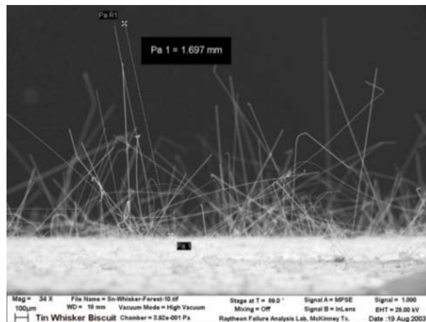
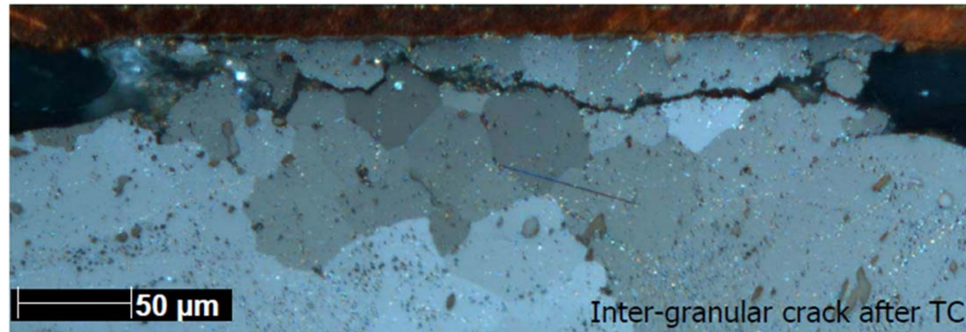
SERDP research reliability research: Lead-free solder and whiskers

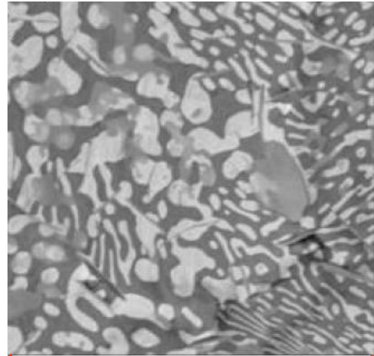




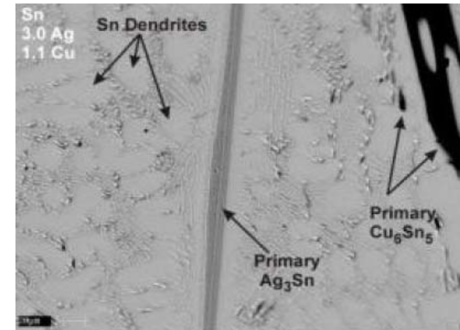
- Lead-free solder
  - Microstructure dependence of Lead-free solder reliability
- Tin whiskers
  - Tin whisker growth on lead-free soldered assemblies
  - Conformal coating tin whisker mitigation
  - 3+ years of testing

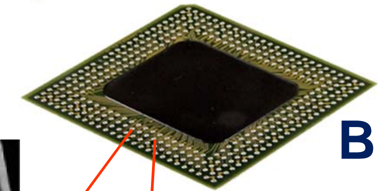
Lead-free Structures are Brittle

Open-circuit Failure Modes

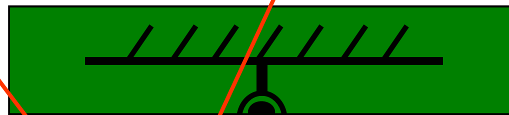


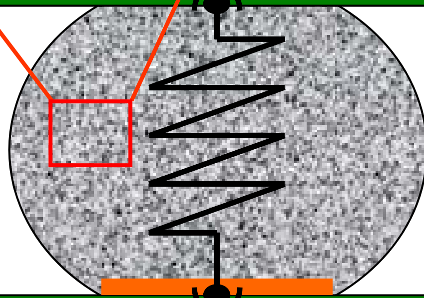
Tin-Lead (SnPb)
Eutectic

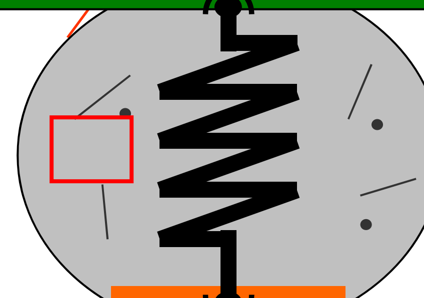




Lead-free SnAgCu
Lead-Free







Failure Modes:

Fractures, open circuit, intermittent contact, ball detachment

BGA failures are obscured, difficult to diagnose & repair

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Tin-Silver-Copper (SAC)

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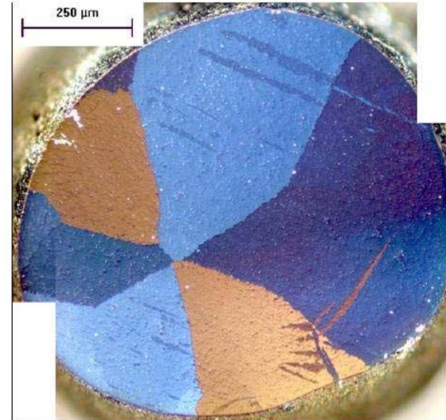
Grain Structure is affected by alloy composition and size

Polarized microscopy of cross-sections shows Tin grain structure

Tin -3.5% Silver

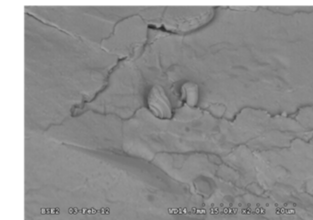


← Tin-3.0% Silver-0.5% Copper

A small amount of copper radically alters the structure of the primary Tin grains.

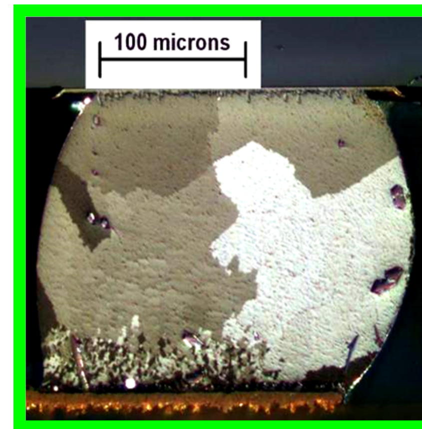
Tin has a crystal structure (grain structure)

Zinc plating grains

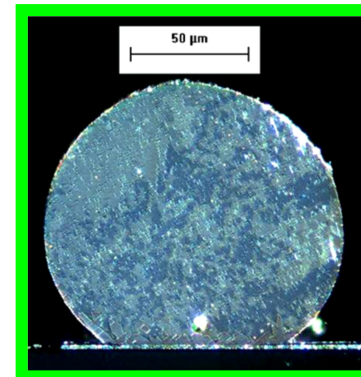


Whiskers and sliding between tin grains in thermal cycling

BGA



Fine Pitch CSP



Flip Chip

Smaller SAC balls contain more smaller crystal grains

Grain structure controls mechanical properties

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Why haven't we heard about consumer electronics failures?

- Some reasons
  - Much shorter lifetime
  - Reluctance to advertise problems
    - Few have heard about Red Phosphorus-Induced Failures in Encapsulated Circuits (http://www.dfrsolutions.com/white-papers/red-phosphorus-induced-failures-in-encapsulated-circuits/)
  - Out of court settlements "data sealed"
- There are lead-free learning curve experiences
  - During the second quarter of fiscal 2009, **NVIDIA** recorded a $196 million charge against cost of revenue to cover **anticipated customer warranty**, repair, return, replacement and **associated costs** arising from a weak die/packaging material set ....

Nuclear, transportation safety, space and DoD are different

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Case study: Accelerated thermal cycling testing

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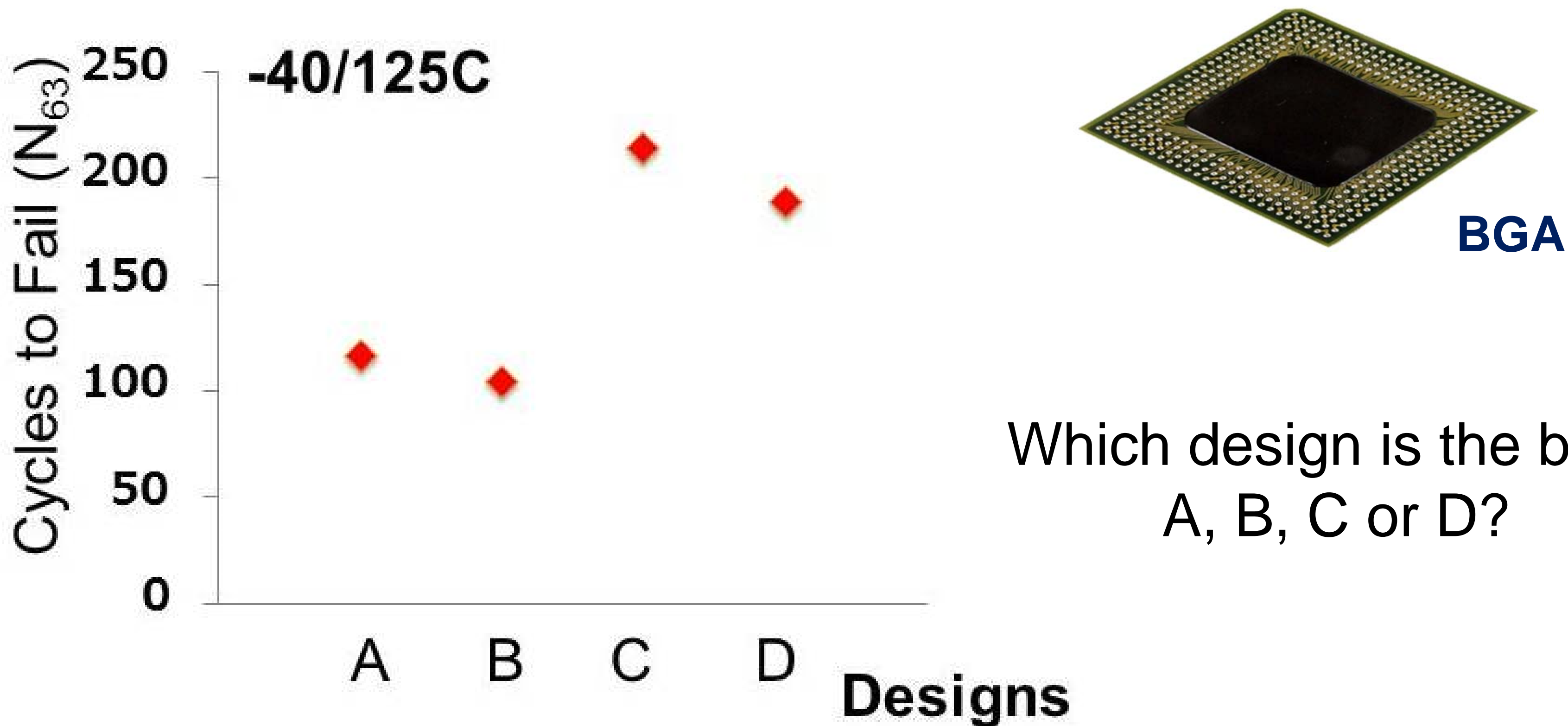
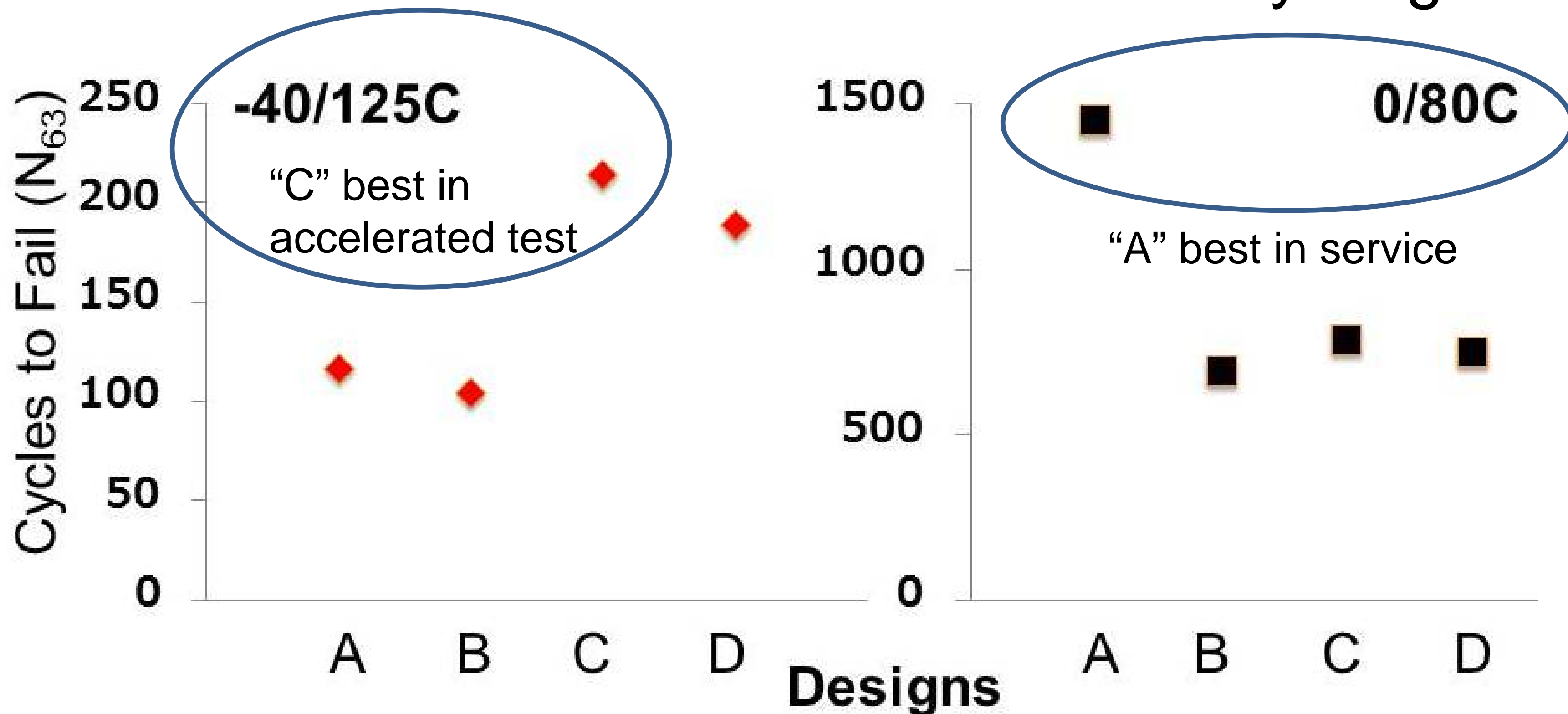
Ex: BGA assemblies in thermal cycling



Which design is the best; A, B, C or D?

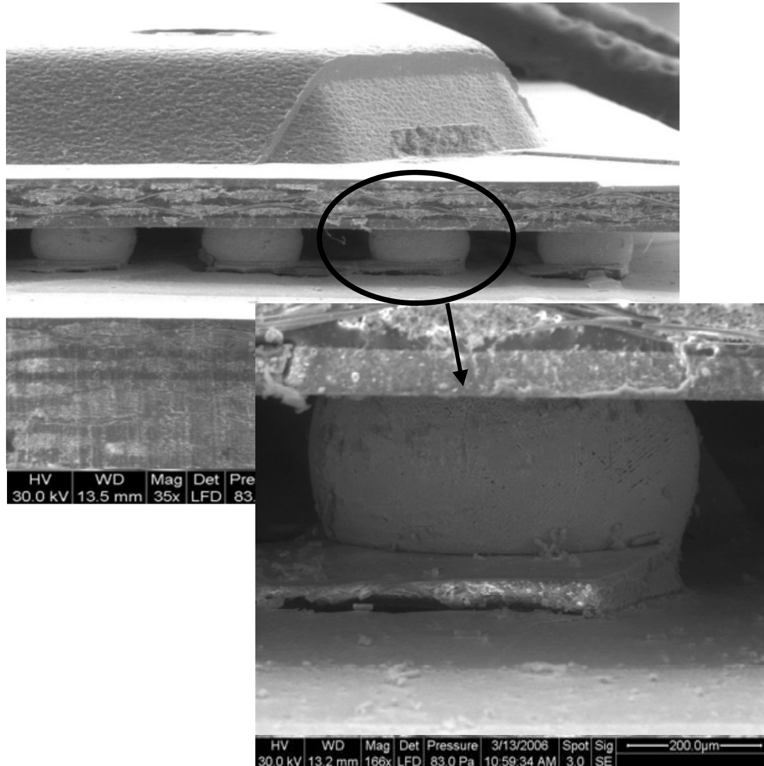
Case study: Accelerated thermal cycling testing

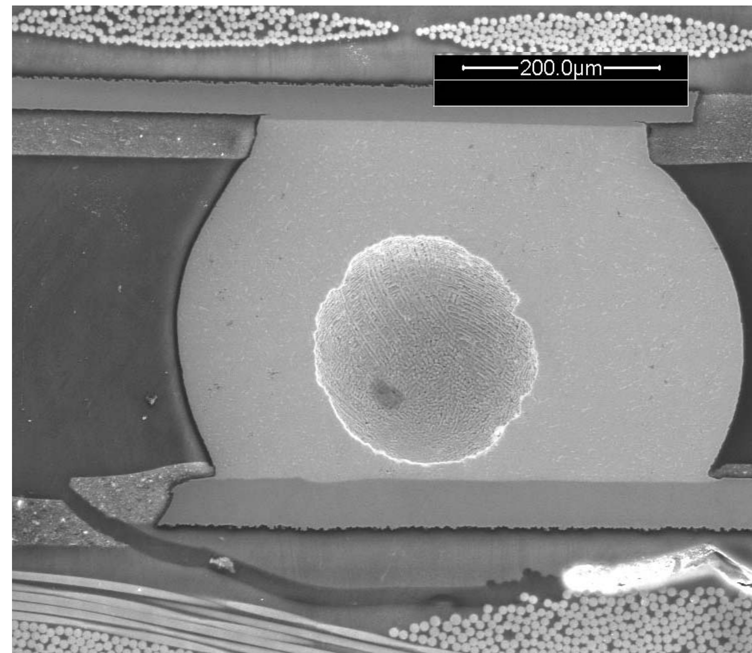
Ex: Lead-free BGA assemblies in thermal cycling



The lead-free design that appeared most reliable in accelerated test was the worst in milder cycle testing

Case study:
Printed Wiring Board Pad Cratering





Pad cratering has become an issue with lead-free BGAs during assembly and under mechanical cyclic loading. Pad cratering usually involved adhesive debonding and cohesive fracture. Higher modulus solder and higher process temperatures make board qualification that much more important. Excessive warpage of BGAs also plays a role.

Pad cratering should be considered a failure, even if still electrically continuous after Vibe/Shock test. It is a latent humidity failure risk.

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Tin Whisker Failure Risk

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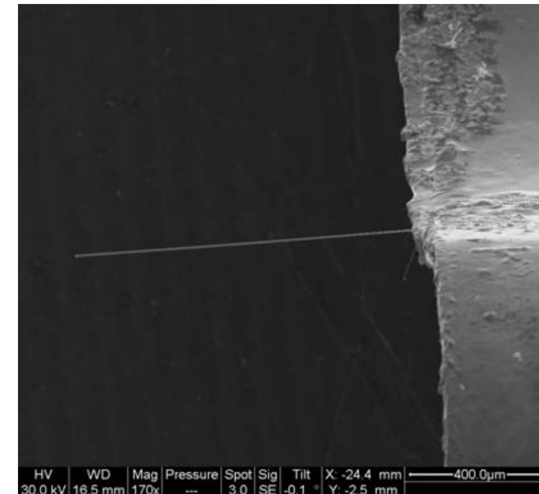
- Tin whiskers are spontaneous growths from tin and high tin content alloy finishes.
  - No electrical bias needed
  - More growth in thermal cycling, humidity/corrosive environments, and long term storage
- Major failure modes of tin whiskers are:
  - Electrical short: permanent (typically <10mA), intermittent (typically >10mA)
  - Metal vapor (plasma) arcing in vacuum and low pressure
  - Contamination
- Tin whisker previously mitigated by Lead but no longer an option
- Various sectors of the electronics industry, including military, medical, telecommunications and commercial applications, have experienced field failures induced by tin whiskers.
- Conformal coating is main mitigation



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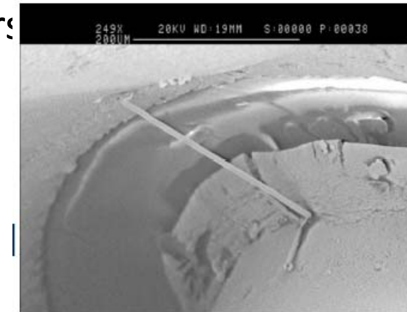
Damage from whiskers induced metal vapor arc in relay

* Davy, G., (Northrop Grumman Electronic Systems), “Relay Failure Caused by Tin Whiskers,” http://nepp.nasa.gov/whisker/reference/tech_papers/davy2002-relay-failure-caused-by-tin-whiskers.pdf, June 10, 2004.

Whisker events in industry

- I heard tin whiskers have been solved
  - In the short term, consumer/commercial component manufacturers have an acceptance test
    - Stated goal – Don't want whiskers longer than 50 microns in 2 years
  - There have been tin samples where whiskers were dormant for years, then grew phenomenal whiskers at 4 years (CALCE)
  - Whiskers grow when the stress conditions are just right
    - Stress too low – no growth, too high – no growth, just the right stress needed
  - Swatch Watch Group
    - As of January 2006, 30% of Quartz Crystal Oscillators Had Tin Whiskers, 5% have experienced short circuits
    - http://www.dtic.mil/ndia/2006dmsms/minter.pdf
  - Growth Mechanisms of Tin Whiskers with Press-in Technology
    - 2012 Continental AG
    - http://rohs.exemptions.oeko.info/index.php?id=177
  - Long term watch items
    - Consumer/commercial part test complacency
    - Cost reduction initiatives



2004 short circuit failure on legacy missile accelerometer

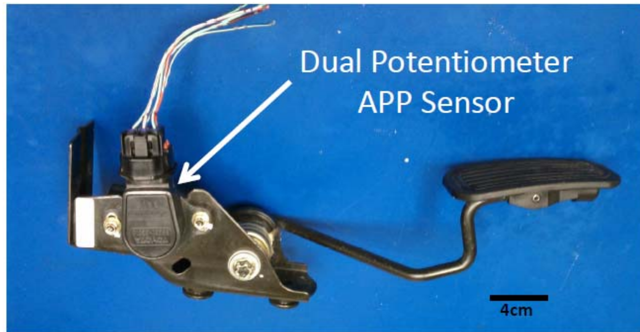
Minter DMSMS 2006

Figure 6 – a) Picture of a spring shape zone type, b) SEM micrograph of the via where the pin has been removed, c) magnified section showing the deformation line and whiskers.

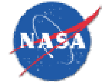
Continental 2012

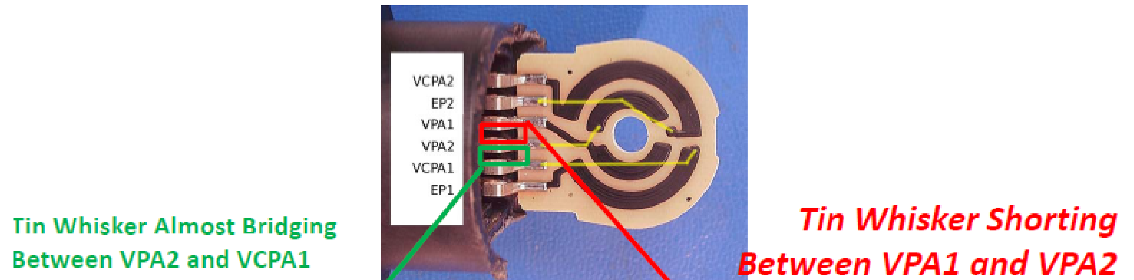
GEIA-STD-0005-2 provides best Mil/Aero consensus for Tin whisker mitigation of commercial parts used in DoD Systems

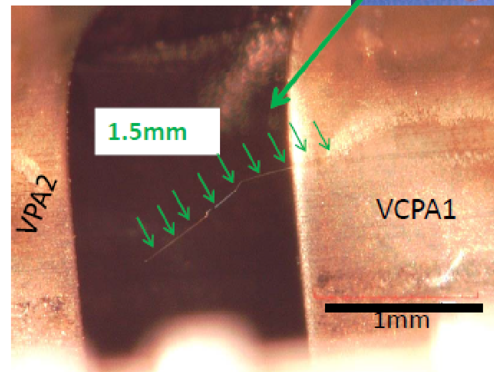
Case study:
Tin whiskers in accelerator sensor failure

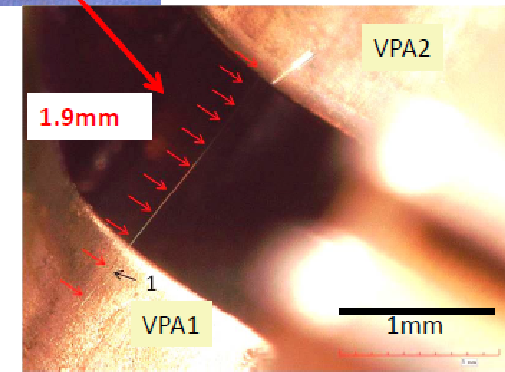


The Two Longest Tin Whiskers Observed
in Faulty 2003 Toyota Camry APP Sensor









9/14/2011 5th International Tin Whisker Symposium 17

Standard digital volt meter can fuse
whisker in less than a millisecond
No – fault found

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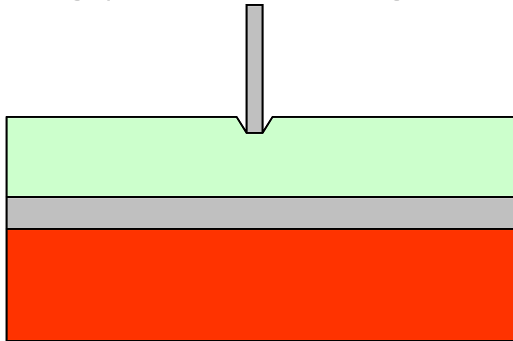
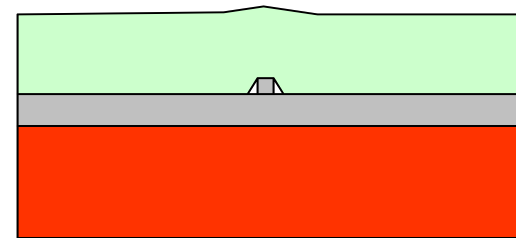
Whisker Mitigation with Conformal Coating

- The conformal coating has been considered as a mitigation strategy for preventing the electrical shorts by tin whiskers
- Coating provides mitigation in two modes



Prevent Contact



Contain Whisker

- Long-term effectiveness of many coatings has not been proven
- Coverage needs to be considered when assessing the effectiveness of mitigation

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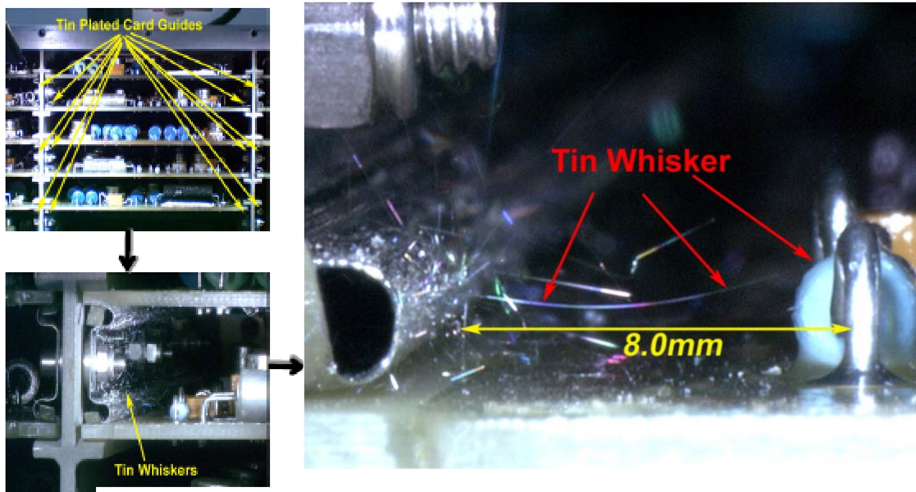
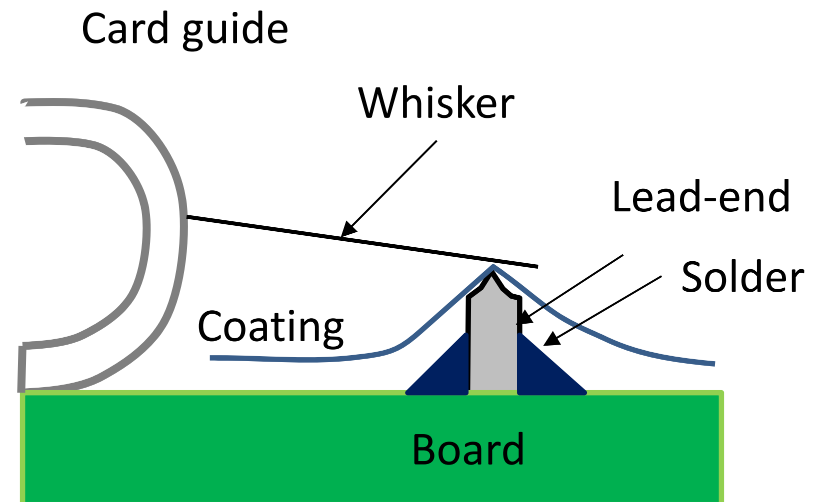
Case study: Conformal coating mitigation

Space Shuttle Flight Control Avionics Box,
20 year old system, no longer in production, many parts obsolete





Thin coating on lead tip

Conformal coating protected electronics from shorting by millions of whiskers
One whisker found a thin coating region and suspected to have shorted

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Three distinct Lead-free problems

- Escalation of acquisition and sustainment cost due to the major global reduction in the availability of leaded electronics materials;
- Risk of failure due to tin whiskers is exacerbated by increased use of pure tin (or majority tin) finishes on components and printed circuit boards; and
- Development of a clear understanding of the system performance and reliability of new Lead-free material sets (e.g. Lead-free solder interconnects, board laminates, part finishes, board finishes, coatings) and the test protocols needed to validate their performance.

Source: 2014 AIA Joint Government and Industry Executive Forum on Lead(Pb) –free Electronics

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It is a DoD issue because…

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- DoD is using lead-free
  - COTs to meets cost objectives and rapid prototype delivery schedules
  - **Levels of mitigations due to varying interpretation of requirements**
- DoD has always flowed down reliability requirements
  - But, they are based on 30 years of tin-lead electronics use and old standards
    - e.g. No tin plating/tin whisker factor in MIL-HDBK-217 reliability calculations
- Want a DoD supply chain change to ensure it is going to get the reliability it wants with the lead-free materials
  - Ask for the right requirements
  - Definition of mission/use environments much more important than ever
- Open item **"Objective evidence for reliability"**
  - Industry consensus still lacking
  - Lead-free materials need analysis beyond the heritage tin-lead
- Sustainment
  - **DoD owns equipment longer than some companies exist**
  - Need to know what materials are used where

DoD needs to be a well informed customer

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Enabling lead-free materials

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- Programs, systems engineering and design team task:
  - **No "as-good-or-better"** industry accepted **lead-free replacement** today for tin-lead solder in all mil/aero environments
  - **How good is good enough?**
- Less harsh environment applications
  - Current lead-free solder alloy designs will likely be satisfactory
  - Use in applications not needing a deep understanding of failure rates
  - Use with whisker mitigation
  - Use in applications with high accessibility
- More harsh environments
  - Use lead-free solder with design features to reduce stresses below traditional tin-lead levels (e.g. stiffening, underfill, staking, …)
  - Modified test protocols to mitigate against aging effects on solder and tin whiskers
    - Develop combined aging, thermal cycling, vibration, humidity tests
  - Commercial industry is working the next generation of lead-free

Continued investment in knowledge and infrastructure is needed for DoD use of lead-free materials

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DETAILED WEBINARS

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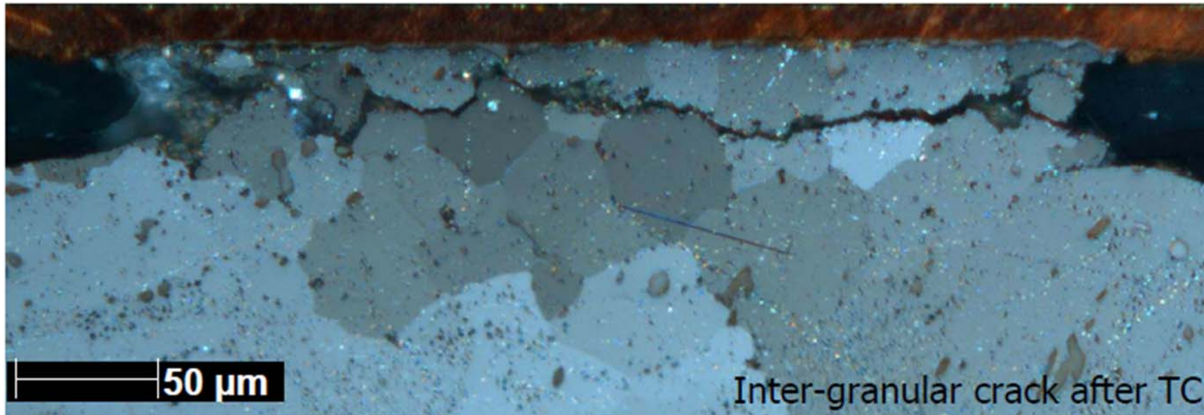
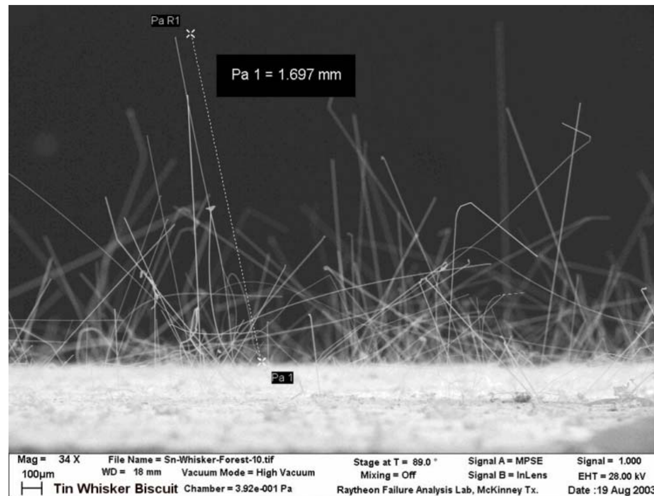
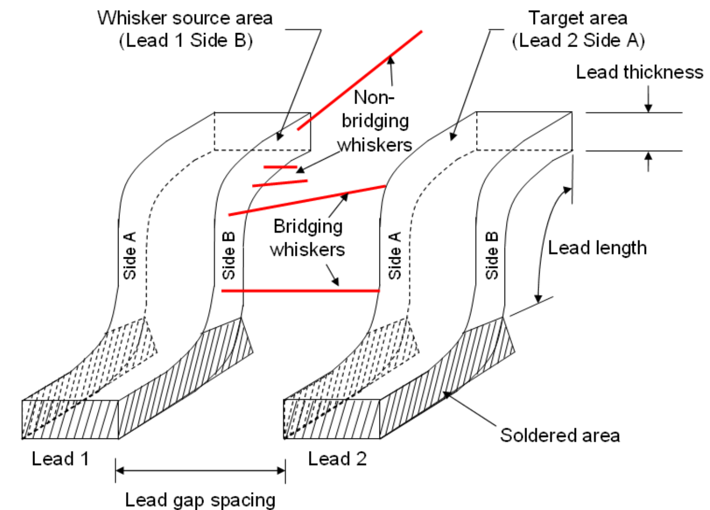
No-Lead Solder Reliability



- Properties are determined by microstructure
- Initial microstructure depends on design and process
- Microstructure keeps changing with specific combination of storage and use conditions
- This leads to surprises and greatly complicates
  - test requirements/protocols and interpretation of results (‘best in test’ often not ‘best in service’)
  - modeling
- Overview outlines mechanistic understanding and practical recommendations – identifies sources for detailed info

Tin Whiskers





- Whisker growth factors, plating and solder
  - Materials, cleanliness and solder thickness
- Failure modes
  - Low voltage and high voltage circuits
- Short circuit mitigations
  - SAE GEIA-STD-0005-2 review with emphasis on conformal coating
- Short circuit risk modeling
- Overview outlines whisker growth observations, mitigation approaches, and risk modeling – identifies sources for detailed info

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Programs Lead-free Action Plan

- **Flow down Lead-free Control Plan (LFCP) Requirements**
  - Data Item: DI-MGMT- 81772
  - Ensure system will function as required in intended operational environments
  - Tin-lead parts are increasingly costly or not available
  - Some applications can use lead-free with current industry knowledge, analysis and mitigations
  - DoD needs to develop additional test standards for harsh military applications
    - Consumer methods insufficient for harsh DoD applications
- **Establish team knowledge**
  - Accurate review of reliability analysis and test
  - Tin whisker mitigation validation
  - Informed lead-free control plan review
- **Leverage Resources**
  - IPC-PERM, SERDP Research, Industry Consortia
  - Defense Acquisition University Training (DAU CLL 007)

Land

Sea

Air

Lead-free risk mitigation and team knowledge needed for DoD electronics

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Questions

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DoD Lead-free resources

- ARMY AMRDEC
  - MIL-STD-11991 (Missile Systems) contractual deliverable using DI-STDZ-81993
- Require LFCP using DI-MGMT-81772
- DMEA - Defense Microelectronics Activity
- NAVY – Office of Naval Research – Best Manufacturing Practices Center of Excellence
- Air Force - Defense Standardization Program Office (DSPO) Parts Standardization and Management Committee (PSMC) participation
- SERDP/ESTCP Research
- Defense Acquisition University
- Lead-free Electronics Portal
  - https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=a5875288-d24c-44ba-b187-fc06c4e6983c)
  - CLL 007 Training Module Lead Free Electronics Impact on DoD Programs
- Acquisition Community Connection
  - https://acc.dau.mil/CommunityBrowser.aspx?id=724437&lang=en-US
- Lead-free Manhattan Project Reports
  - https://acc.dau.mil/CommunityBrowser.aspx?id=336265
- DoD Soldering technologies working group
  - https://acc.dau.mil/adl/en-US/353254/file/49357/STWG%20Understanding%20Lead-free.pdf

DoD Lead-free resources

- DoD Soldering technologies working group
  - https://acc.dau.mil/adl/en-US/353254/file/49357/STWG%20Understanding%20Lead-free.pdf
- DoD Documents
  - Lead standardization Activity for Solder
    - LSA SOLD-08-01 – DoD Soldering Technologies Working Group
    - LSA SOLD-08-02 – Manage by avoidance, inspection, and control plans
    - LSA SOLD-08-03 – Tech guidance and control plan for rework and repair
    - LSA SOLD-08-04 – USDoD Lead-Free Control Plan (templates -05/-06)
    - LSA SOLD-08-07 – Risk Management
    - Naval Surface Warfare Center Instruction NSWCCRANEINST 4855.18C

Lead-free research resources

- SERDP/ESTCP – DoD Strategic Environmental Research and Development/ Environmental Security Technology Certification Program
  - Lead Free Webinar Slides
  - Microstructurally Adaptive Constitutive Relations and Reliability Assessment Protocols for Lead Free Solder
  - Novel Whisker Mitigating Composite Conformal Coat Assessment
  - Tin Whisker Testing and Modeling
  - Contributions of Stress and Oxidation on the Formation of Whiskers in Lead-Free Solders
  - Tin Whiskers Inorganic Coatings Evaluation (TWICE)
  - The Role of Trace Elements in Tin Whisker Growth
- Auburn University - Center for Advanced Vehicle and Extreme Environment Electronics
  - Various projects studying lead-free solder reliability and tin whiskers including studying drop shock and aging effects
- Binghamton University - Integrated Electronics Engineering Center (IEEC)
  - Various projects studying lead-free solder reliability, tin whiskering and conformal coating mitigation
- Joint Council of Aging Aircraft (JGPP) Lead-free testing completed on four lead-free solder alloys. Results published
- Sandia National Labs and Ames Labs
  - Lead-free solder alloy development and tin whisker research
- NASA – Jet propulsion lab
  - Working on IPC standards for lead-free assembly reliability test protocols
- NASA – Kennedy Space Center
  - TEERM Office NASA-DOD Lead-Free Electronics (Project 2) Project Number: NT.1504NASA – DoD Phase 2 and Phase 3
- NIST
  - Archive of solder properties
- National Defense Center for Energy and Environment (NDCEE)
  - Demonstration/Validation Testing of X-Ray Fluorescence (XRF) Technology to identify Lead-free Electronics and Solder Categories
  - Development of Lead-free Training Courses and a Lead-free database
- Universal Instruments Corp. - Advanced Research in Electronics Assembly (AREA) Consortium
  - Various projects studying lead-free solder reliability with an emphasis on manufacturing processes and microstructure
- University of Maryland – Center for Advanced Life Cycle Engineering
  - Several project and tools related to Lead-free and Tin Whiskers

Lead-free Control Plan
Data Item Description (DID)

Title: Lead-Free Control Plan (LFCP)
Number: DI-MGMT- 81772
Approval Date: 20090612
AMSC Number: N9072
DTIC Applicable: N/A
Office of Primary Responsibility: SEA04RM
Applicable Forms: N/A

Use/Relationship: The Lead-Free Control Plan (LFCP) will be used to obtain essential information from contractors on how they plan to manage the risk of lead-free solders or finishes used in their products during the program's lifecycle.

This DID contains the format and content preparation instruction for the data product generated by the specific and discrete task requirement as delineated in the contract.

This DID is applicable to all new contracts and solicitations that acquire electronic systems including weapons systems containing electronic components as well as rework or repair of electronic systems or components.

The DID may also be applicable to systems already in production for major changes and block upgrades.

The reference documents cited in this DID, GEIA-STD-0005-1, "Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-Free Solder" and GEIA –STD-0005-2, "Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems", may be obtained from: Government Electronics and Information Technology Association, 2500 Wilson Boulevard, Suite 1100, Arlington, VA 22201, or as specified in the contract.

Requirements:

1. Reference documents. The applicable issue of any documents cited herein, including their approval dates and dates of any applicable amendments, notices, and revisions, shall be as specified in the contract.

2. Format. The LFCP shall be presented in the contractor's own format.

3. Content. The LFCP shall contain all of the information specified in GEIA-STD-0005-1 and GEIA-STD-0005-2.

3.1 Lead-Free Solder and Finishes. The plan shall address all lead-free solders and lead-free tin finishes in delivered products.

3.1.1 Reliability. The processes and materials utilizing lead-free solder or finishes shall be identified as capable of producing items that meet product reliability requirements.

3.1.2 Configuration Control and Product Identification. The configurations of all systems, assemblies, subassemblies, and parts shall be included and identified by version and applicable configuration identifier.

DI-MGMT-XXXX (Cont'd)

3.1.3 Risks and Limitations of use. Any risks or limitations on the use of the products due to the incorporation of lead-free solder or finishes shall be identified along with information on how to manage those risks or limitations.

3.1.4 Tin (Sn) Whiskers. Any harmful effects of Sn whiskers resulting from use of lead-free tin shall be addressed.

3.2 The plan shall contain any recommendations or changes to the product design and any contract modifications required to comply with the LFCP.

End of DI-MGMT- 81772