Lead Free Reliability Testing

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Reliability Implications of Lead-Free

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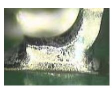
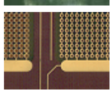
Reliability, of what?

- Solder Joints



- Laminate



- Components

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Solder Joint Reliability

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SAC vs. SnPb

- SAC main alternative alloy
- Comparison is desired, which is most reliable?

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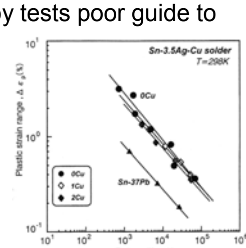
Bulk Solder Fatigue Life

- Lead-free superior by order or magnitude
- Reliability tests on soldered assemblies do not agree
- Isothermal bulk alloy tests poor guide to assembly reliability

Why?

- Joint Geometry (surface and intermetallic effects)

- Thermal excursions



Y. Kariya et al: J. Electronic Materials, 1998, 27, p1229-1235

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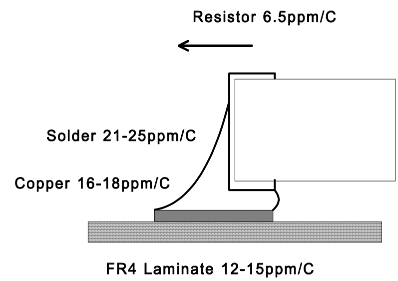
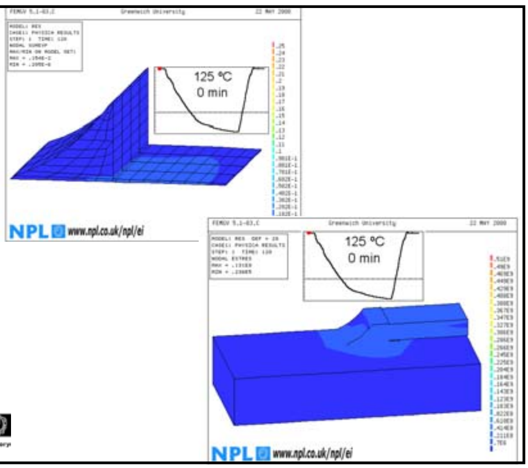
Solder Joint Reliability

- Wear out mechanism is thermal fatigue
  - Different TCE of the various parts
- Shear strain

Material	TCE (ppm)
SnPb	21
FR4	18
Cu	17
ceramic	6
silicon	2.8

CTE Mismatch – Low Fatigue Cycling

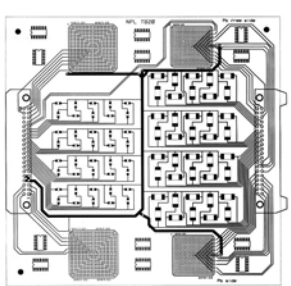




Components and Test Vehicle

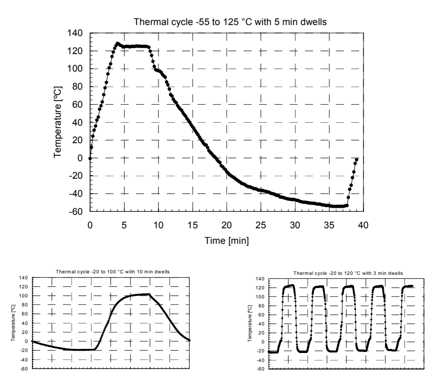
- Small and leaded components do not induce significant global strain
- Large, direct attach, ceramic
  - Large global strain
  - BGA, flip chip, discrete, ceramic, silicon
    - Connectors, fillet lifting
- Dummy components
  - LF terminations

Test Vehicle



- 2 x PBGA672 1mm pitch
- 2 x PBGA484 1mm pitch
- 12 x SOIC 1.27mm pitch
- 20 x Resistors 2512
- 20 x Resistors 0805
- 2 x 40-Way Connectors

Thermal Cycling



NPL Lead-Free Evaluation

- Three solders

Solder	Composition	Meting point [°C]
A	Sn63Pb37	183
B	Sn95.8/Ag3.5/Cu0.7	217
C	Sn62/Pb36/Ag2	~ 179

- Two PCB surface finishes (AuNi, Cu)
- Four component lead types (chip termination, gull wing, pth, balls)

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Experimental Matrix

	OSP (Cu) Board	AuNi Board
Lead-Free Solder	Sn Resistors PdNi SOIC SnAgCu PBGAs AuNi Connectors	Sn Resistors PdNi SOIC SnAgCu PBGAs AuNi Connectors
	SnPb SOIC SnPb PBGA SnPb Resistors	SnPb SOIC SnPb PBGA SnPb Resistors
Lead Solders	Sn Resistors PdNi SOIC SnAgCu PBGAs AuNi Connectors	Sn Resistors PdNi SOIC SnAgCu PBGAs AuNi Connectors
	SnPb SOIC SnPb PBGA SnPb Resistors	SnPb SOIC SnPb PBGA SnPb Resistors

Lead-free assembly

Lead transition assembly

Leaded assembly

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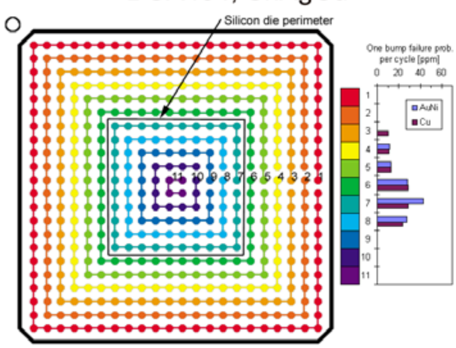
BGA484, SnAgCu



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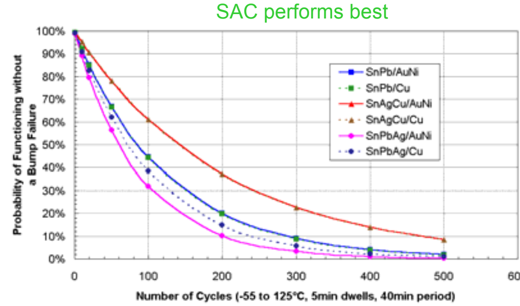
PBGA 484 Reliability

SAC performs best



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PGBA Reliability Summary

- Bumps located at the die perimeter are more prone to fail
- Pb-free solder most reliable solder
- No significant evidence that solder joints on Cu PCB finish can be more reliable than on AuNi

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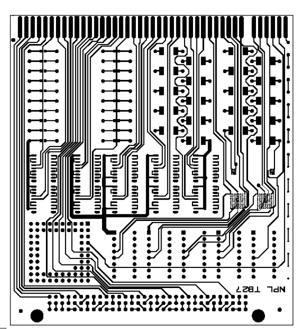
Reflow test board



Components:

- 20x 2512 resistors
- 20x 0603 resistors
- 10x SOIC
- 2x CSP
- 2x BGA
- 1x TH Connector
- 20x vias

Stencil:

- Material: Stainless steel base thickness 100µm, Ni additive area 200 µm
- Solders:
  - SnPb
  - Sn93.5Ag3.8Bi2Cu0.7
  - Sn95.5Ag3.8Cu0.7

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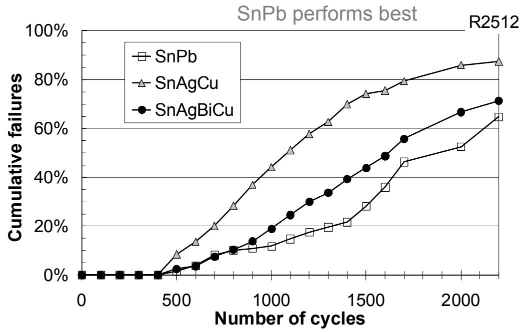
Resistor 2512



5 board finishes averaged

Conclusions - Continuity Testing

- Alloys respond differently in different strain ranges. *SnPb can accommodate more strain, but SAC will be more reliable in low strain environments*
- Addition of Bi into SnAgBiCu alloy has a benefit on reliability, especially for higher strains

Other Assesment Tools

- Shear Testing
  - After thermal cycling, can detect crack growth prior to complete lack of continuity (reduction in Ultimate Shear Strength)
  - Quick and low cost
- Microsectioning
  - See changes in microstructure and crack growth
  - Very labour intensive

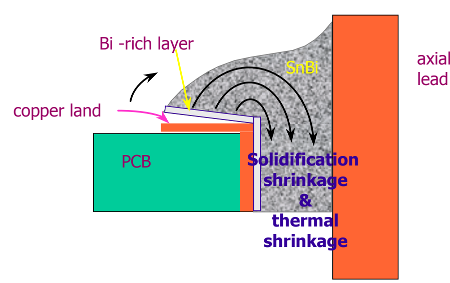
Design Choices?

- There is no 'best alloy' SAC performs best under lower global strain situations (majority of cases today)
- SnPb is able to absorb strain through creep and performs better in high strain situations
- Global TCE issues for components are more important for SAC, design compliance into leads/geometry if possible

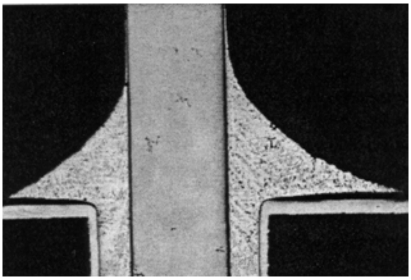
Specific Joint Reliability Concerns

- Lead Contamination
- Fillet Lifting
- Mixes of alloys in rework
- Effect of PCB finish

Schematic of Lift-off

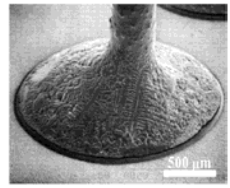


Microsection of fillet lifting



Courtesy of NCMS study

Fillet Lift-off



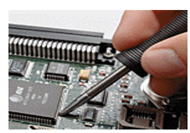
Ref: K. Suganuma, IMAPS, Harrogate 1999

- Fillet lifting is considered a benign defect
- Pad lifting is considered a harmful defect, as pad movement could break track connection
- Seen more with Bi containing SAC based alloys and non-eutectic reworked joints

Effect Rework and Lead Contamination Effects

Impact of Lead-Free on Rework

- Un-harmonized introduction of alternative alloys
- Board assemblers utilising a range of alloys
- Difficult to determine alloy of manufacture
- Sub-assemblies manufactured, reworked and repaired at various locations
- Solder mixtures may be created



What is the impact of this on joint reliability?

NPL Project

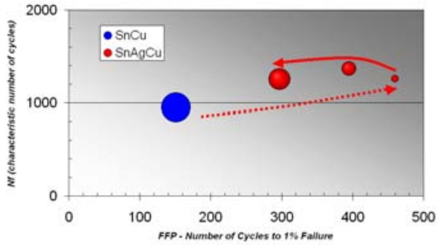
- Solder pastes with lead and lead free alloys mixed to simulate alloy mixes in a reworked joint (25% and 50% levels)
- Paste mixtures used to manufacture SM test boards
- Reliability of joints assessed using:
  - Thermal cycling with continuity testing
    - Joint shear testing
    - Microsectioning
- AIM – to determine the effect of mixing alloys on reliability of electronic assemblies

Test Materials

- 5 different solders used, 3 lead-free and 2 lead containing.

Solder	Composition	Melting Point (^oC)
SnPb	64%Sn/36%Pb	183
SnPbAg	63Sn/ 37SnPb/ 2Ag	~179
SnAgCu (Common)	95.8Sn/ 3.5Ag/ 0.7Cu	217
SnAgBiCu (Alternative)	93.3Sn/ 3.7 Ag/ 2.1 Bi/ 0.8 Cu	210
SnCu (Wave)	99.3 Sn/ 0.7 Cu	227

Role of Intermetallics



- Alloy mixtures generally have better FFP than single alloys
- Due to presence of intermetallic precipitates ($AgSn_3$ in above example) not present in 'single phase' eutectic alloys
- Intermetallic compounds can impart additional structure and strength to the solidified joint
- Confirmed by microsections…

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Rework Conclusions

- Mixed alloy joints in this study generally gave better or equal first failure performance relative to the original alloys
- There is a potential for increased fillet tearing and pad lifting with alloy mixtures, although the defects proved benign in the NPL study
- Evidence that lower lead levels can be harmful…

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Lead Contamination

- Using SnPb plated component leads with lead free risks…
  - Concentration of Pb rich low melting point phase around lead-solder interface
    - LMP could be a risk in terms of increased rate of crack growth
    - Secondary reflow on double sized board more likely to occur

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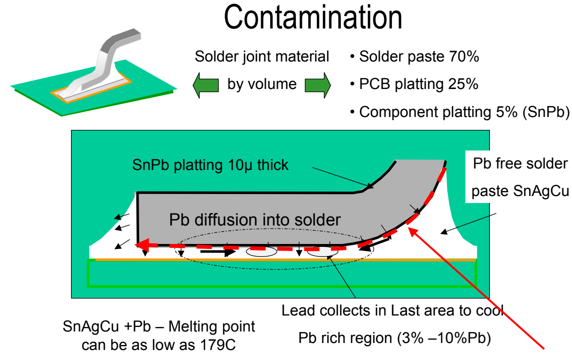
Lead-free Joint Failure via Lead Contamination



Crack propagation pathway induced by thermal cycle fatigue

Source: Transition to Lead – Free Components & User induced Component Failures, Angus Westwater - Rohm Electronics

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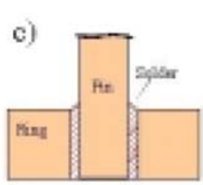
Swedish Institute for Metals Research

- Subsequent plug & ring low cycle fatigue mechanical testing
- 1, 2, 5,10,15 & 20 Pbwt% added, 0.5m joint thickness
- Room temperature
- +/- 5 μm, ~60 cycles per hour



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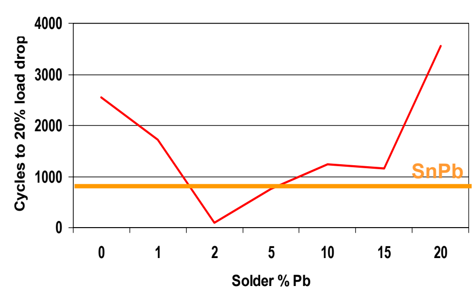

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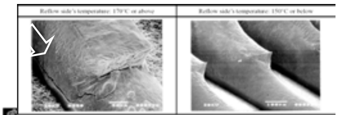
Reflow Followed by Flow (wave) Process

(Lead contamination of top side solder)

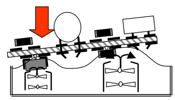
- SnAgCu topside solder paste
- Top side SMD components SnPb plating.
- Bottom side flowed at approx 245°C
- There is a high risk of component lifting when top side temperature exceeds 170 °C during bottom side flow.

SnAgCu + Pb alloy = lower melting point than SnAgCu

Top side temperature max = 150°C



Courtesy Seiko Epson



Source : Rohm

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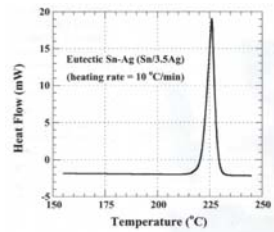
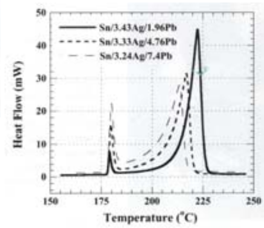
Michigan State University



"..the existence of the low melting point phase would be disadvantageous when the eutectic SnAg solder is used for higher temperature applications such as under the hood circuit boards."



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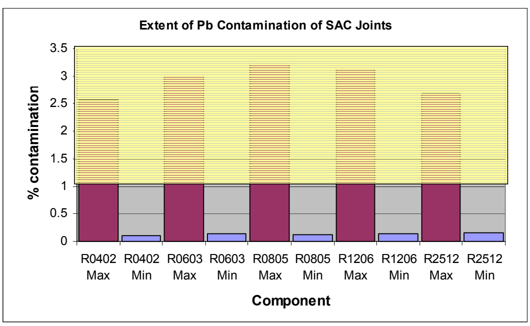
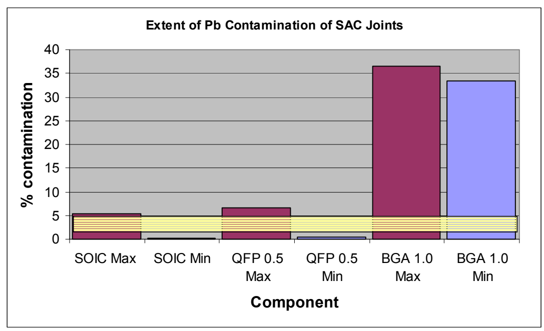


Assumptions : typical plating thicknesses, stencil thicknesses, IPC pad layouts, complete mixing of plating and paste



Assumptions : typical plating thicknesses, stencil thicknesses, IPC pad layouts, complete mixing of plating and paste

Quick Test for lead in terminations?

- Chemical indicator test based on Sodium Rhodizonate
- Commercially available kits based of tests for lead-paint
- Work still to be done to confirm effectiveness in practice

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Laminate Reliability

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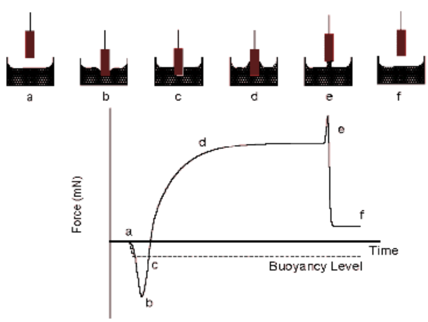
Representative Reflow Conditions

	SnPb profile	lead-free profile
Max temp reached (degC)	219	253
Average Time above 185°C (secs)	56	140
Average Time above 217°C (secs)	5	62

Solderability of ENIG Finish

- Concern
  - Does multiple PbF profiling reduce solderability below that expected with SnPb profiling?
- Work
  - Age test substrates through multiple PbF & SnPb profiles and undertake subsequent solderability testing (globule and dot pattern).

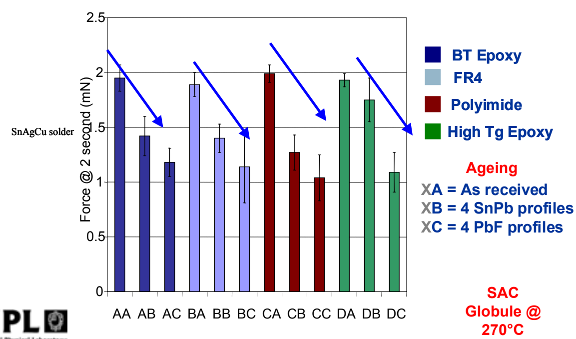
Wetting Balance



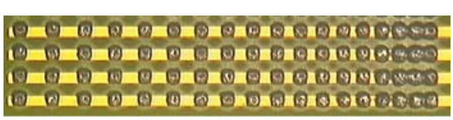
High Wetting Force = Good Solderability

Wetting Force - ENIG

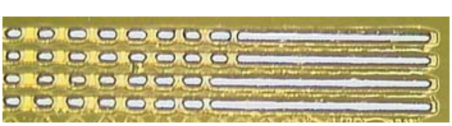
As received and after four SnPb & PbF profiles



Dot Solderability Testing



After printing

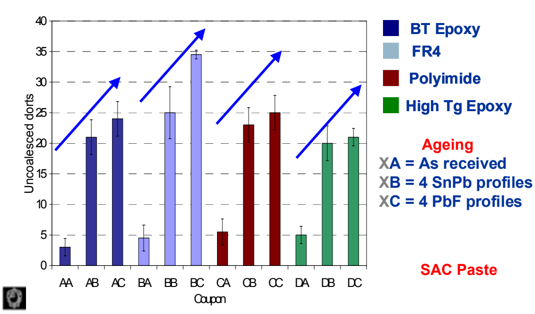


After reflow

Low No. un-coalesced dots = Good Solderability

Dot Testing - ENIG

As received and after four SnPb & PbF profiles



Conclusions

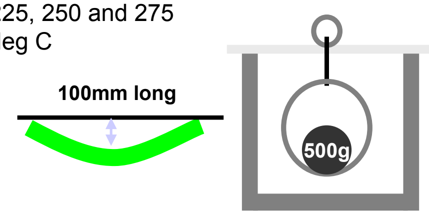
- Increased degradation with PbF reflow soldering for both globule and dot testing
- Need to be aware of this for multiple pass reflow

Propensity to Warp

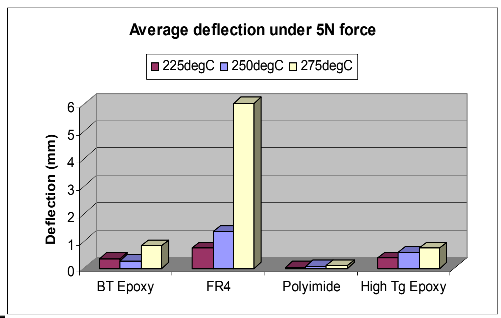
- Concern
  - Does PbF profiling increase board warp above that expected with SnPb profiling?
- Work
  - Subject samples of base laminate types to 3 point bend test at SnPb and PbF soldering temperatures

Deformation Measurement

- Sample and jig placed in air circulation oven for 15 minutes at 225, 250 and 275 deg C



Deformation Results



Conclusions

- Higher temperatures promote deformation under load
- Only Low Tg FR4 greatly affected
- Board clamping and support through reflow may become more critical

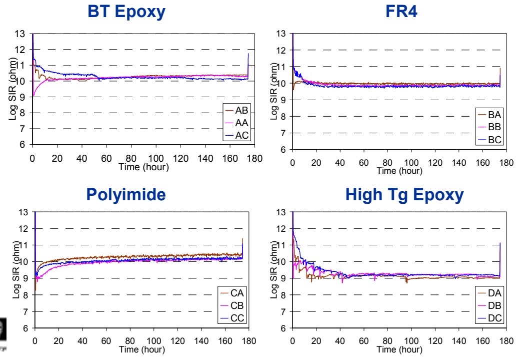
Surface Electromigration

- Concern
  - Does PbF profiling increase susceptibility of product to surface electromigration above that expected with SnPb profiling?
- Work
  - Subject base laminate types to SIR testing at SnPb and PbF soldering temperatures with and without typical flux present

Effect of Base Laminate

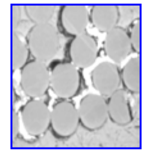
85°C/85%RH

XA = As received
XB = 4 SnPb profiles
XC = 4 PbF profiles



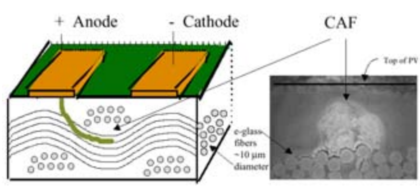
CAF

- Concern
  - Does PbF profiling increase susceptibility of laminate to subsurface filament failure modes compared with SnPb profiling?
- Work
  - Subject base laminate types to CAF testing at SnPb and PbF soldering temperatures



Conductive Anodic Filamentation

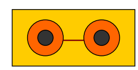
- A phenomenon seen within the weave of epoxy-glass PCA substrates



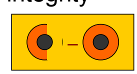
Ref Laura Turbini, Georgia Tech

CAF Failures

- Evidence shows that CAF occurs in multi-layer FR4 boards between vias or vias and power or ground planes
- Field failures results because:
  - Filament creates a reduction in insulation resistance

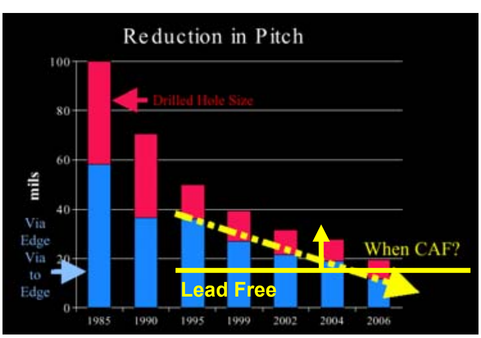


  - Dissolution destroys Anode integrity



Filament grows from **Anode to the Cathode** made from copper salts, not from a metallic dendrite

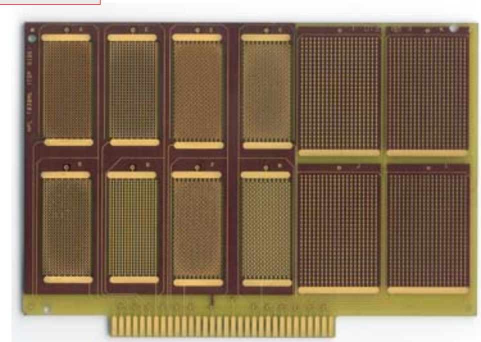
Sun Micro Road Map



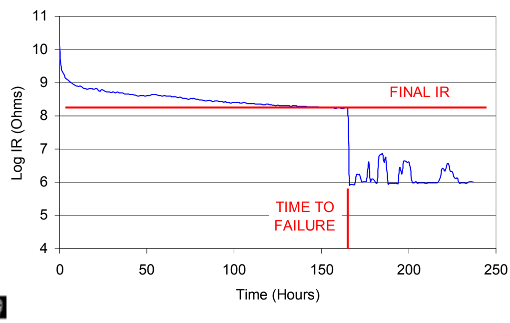
Courtesy of Sun Microsystems

CAF Test Vehicle

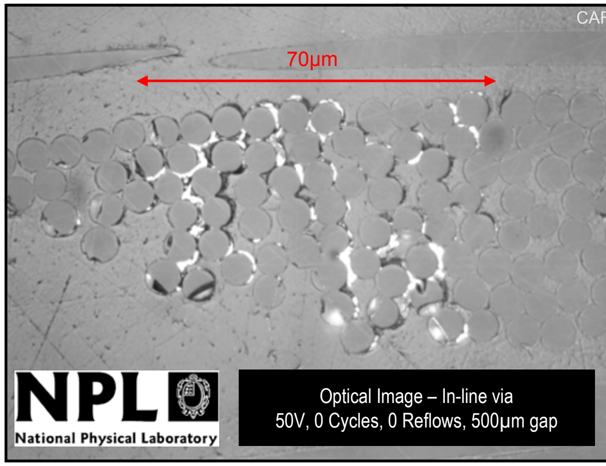
6000 Vias



Time to CAF Failure and IR



CAF



CAF

CAF Tips

- LF processing increases CAF
- Warp/Weft have different effects
- Staggered vias offer protection
- Time to Failure decreases exponentially as distance decreases
- Moisture is main driver

Thank you for your attention

www.npl.co.uk/npl/ei