

This version of this presentation has proprietary Alcatel-Lucent, HDPUG, and UIC Information/data removed. As such it doesn't always make sense...



Reliability Knowledge Gaps

For use of Pb-free solders in High Reliability Applications



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What is Reliability?

And the Implications of this Definition for Pb-free (SAC) solders

Reliability of the solder joint of a particular package is defined as the **probability** that the solder joint will perform its intended function for a specified period of time, under a given operating condition, without failure. (Dr. John Lau)

In Telecom (as an example) we expect:

- 25 year life in Central Office Conditions
- 20 year life in Outdoor Telecom Conditions
- 100ppm failure rates (or less) at End of Life

Other industries (such as Medical, Aerospace) may have much more severe criteria

Implications

- We must be able to predict the reliability of the solder joint
 - We need a valid (industry agreed) model that encompasses
 - Key factors affecting reliability
 - Acceleration Factors that relate accelerated tests to field conditions
- Alternatively - IF we could state something to the effect of “SAC outperforms SnPb solders” 100% of the time THEN we could use the SnPb model as a conservative estimate as a better model was developed
 - Unfortunately - as you’ll see, this is NOT the case

Gap Number 1 - No VALID (industry agreed) Model for SAC Solder Joint Reliability

Even in Accelerated Tests, SAC often SIGNIFICANTLY Worse

Contrary to many published statements, SAC solder joint reliability, even in accelerated testing, is quite significantly reduced compared to equivalent SnPb components in some cases

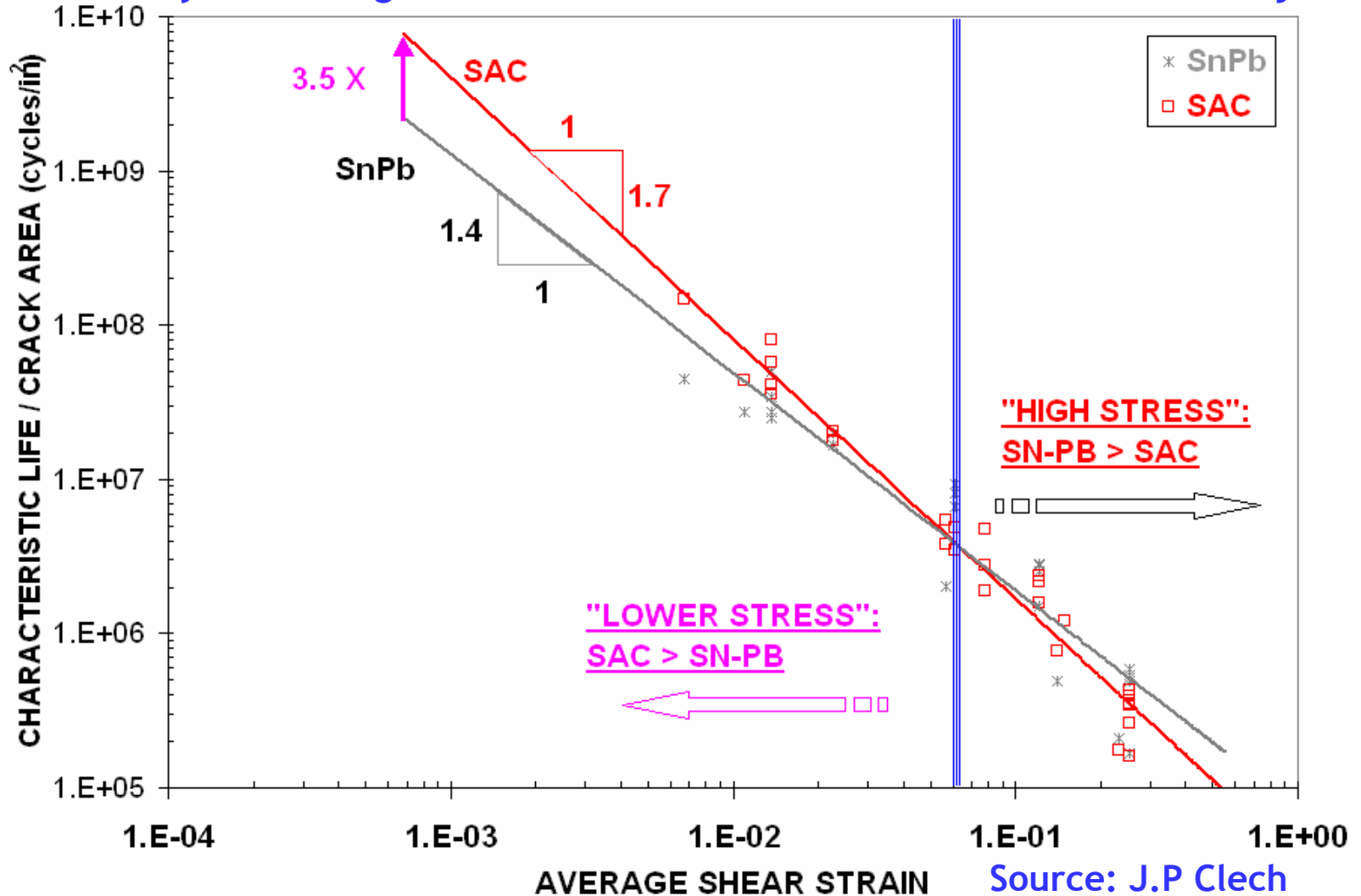
- “Seems” that components with smaller solder joints more often are worse
 - Crystallography effect? (TBD) - we don’t fully understand why this is so at this time
 - Small BGA (0.8, 0.5mm pitch) - example top left
 - QFN - example bottom left
 - Smaller Beta = Wider distribution of the failures

- Some larger components also problematic
 - Example: CuCGA compared to CCGA routinely has earlier failures
 - High Strain Components

Currently there is No Way to quantify what this means to field reliability!

High Stress/Strain Components - Fail faster in Accelerated Testing with SAC

Induced by the testing? Or also true in the field? TBD – HDPUG Mild AF Project



Example High Strain Components -N50

Note: Contrary to Some Other Circulated Data – it is NOT just in wide thermal cycles
The 0-100°C Tests are circled for reference

Infineon QFN48
0-100C 20min dw
LF/SnPb
2004/2637 (N63%)

NEC A42 LQFP
LF/SnPb
3500/4500

IBM 32x32mm
1.27CBGA
-40-125 240min TC
LF/SnPb
0.73/1 (norm)

NEC 27x27
1.27BGA
LF/SnPb
3700/6000

Raytheon CSP100
-55-125 15min dw
LF/SnPb
140/240

Raytheon 20CLSS
-55-125 15min dw
LF/SnPb
250/360

IBM 32x32mm
1.27CBGA
-40-125 42min TC
LF/SnPb
0.84/1 (norm)

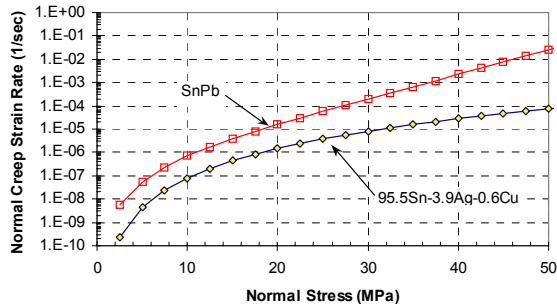
HDPUG
1657CCGA
0-100 40min TC
LF/SnPb
2800/3900

Raytheon TSOP50
-55-125 15min dw
LF/SnPb
370/500

Raytheon 225 BGA
-55-125 15min dw
LF/SnPb
340/460

SAC does not perform like SnPb

SAC \neq SnPb



■ Properties are very different

- Creep rate is much slower (changes with time!)
- Crystallography very different and has effect on results
 - Anisotropic Sn
- Reliability results in accelerated T/C tests vary with
 - Stress levels
 - Strain levels
 - Alloy dependent
 - Dwell dependent
 - Aging effects significant (not fully understood)
 - Interactions of Alloy, Dwell, and Strain are as important - or more important than the main effects!
- Scatter in test results with SAC > SnPb

Much to Learn Here!

SAC Properties Change over Time

Dramatic difference in creep behavior for room temperature aging over several months

How does this affect Fatigue Behavior?

SAC Thermal Cycle Fatigue Performance also Changes with Ageing (Unlike SnPb)

The creep and fatigue properties of SAC solder change with time!

After only 10 days at 125C, thermal cycle reliability of SAC solder joints greatly reduced

- Grain structure is coarser after aging – **fails faster!** Also a Silver intermetallic effect (unsure which is primary concern)
- 2004 paper had previously identified the grain structure and creep change performance over time
 - Confirmed also happens at Room Temp
 - Impact on reliability/fatigue not studied

Understanding of aging effect - room temperature vs. elevated temperature greatly lacking. Much to learn here.

- Note: SAC 387 \neq SAC 305 and the effect of ageing is also different

Not Baked

Baked

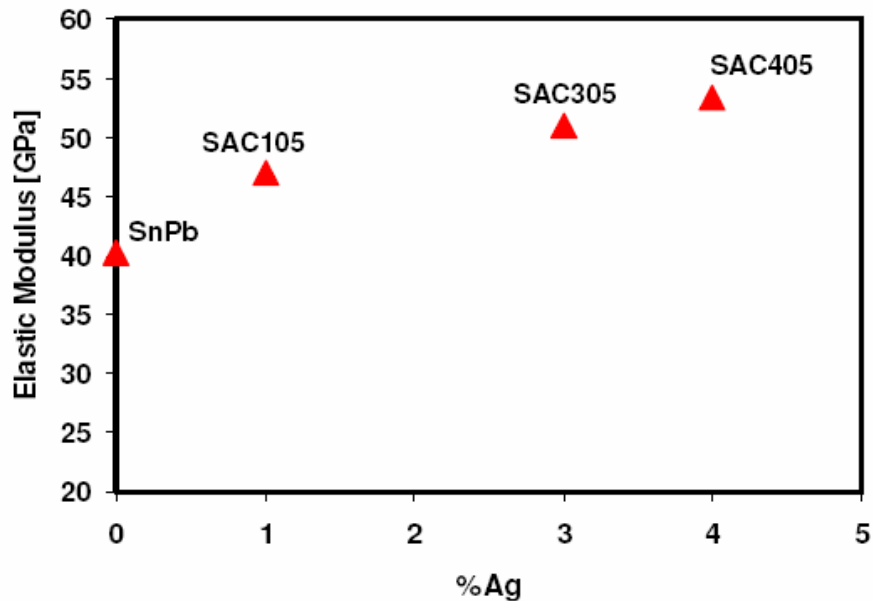
What do these changes in properties mean to all the T/Cycle data already collected without aging? Better or Worse? TBD!

Proliferation of Alloys → They are NOT the Same

Proliferation of Alloys has made characterization a moving target!

- SAC 405, 396, 387, 305, 205, 105N, and SnAg are all being used for solder balls
- Suppliers have introduced new alloys to address specific issues

UIC Data



Source: Intel, "Finding Solutions to the Challenges in Package Interconnect Reliability", Electronic Package Technology Development, 2005

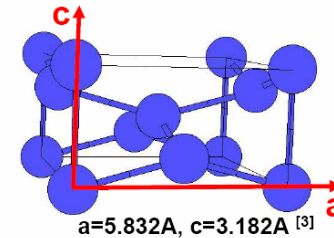
Modeling SAC Very Difficult

Simple Constitutive Relations Will Fail Under a Number of Circumstances

T Cycle Early Failures – Cracked balls away from largest DNP. In the example below, failures locations marked with X

Tin has highly Anisotropic Thermomechanical Properties

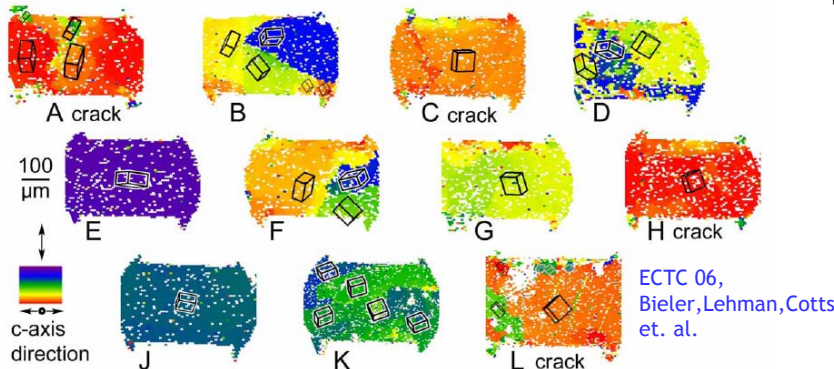
Crystal axis	CTE ppm/°C	Young's modulus (GPa)
[100] a-axis	15	24
[001] c-axis	30	68



Pb free solders cannot be considered as homogeneous media. Variations in Sn grain morphology result in variations in the thermomechanical response of SnAgCu solder joints.

Small changes in Cu content affect Sn grain size and precipitate morphology

Behavior Correlates to Microstructure



Distinct correlation between Sn grain orientation and propensity for failure.

Microstructure is also significantly affected by:

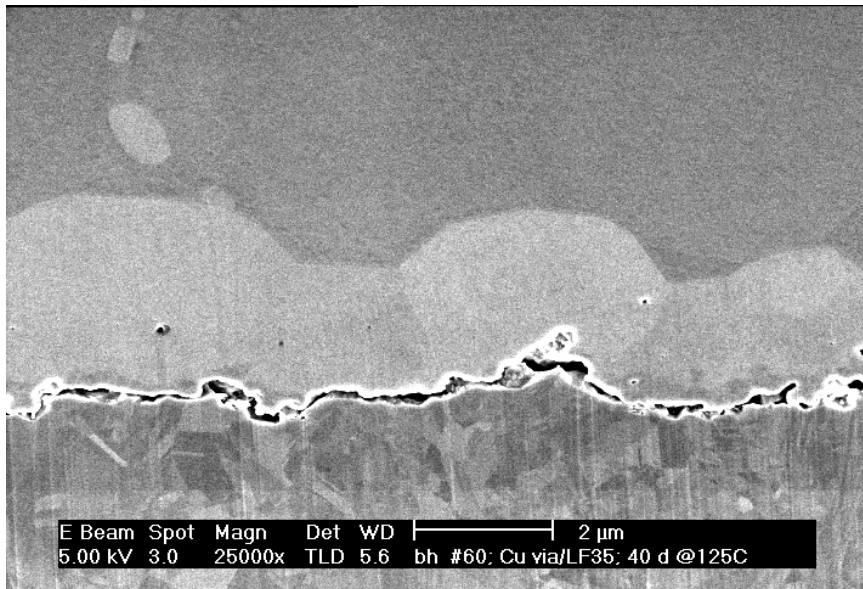
- Reflow Time and Peak Temperature
- Solder Joint Size
- Cooling Rate
- Metallization Chemistry

Intermetallic Interface Issues

(Probably NOT a “show stopper” to going Pb-free - but significant)

SAC is much “stiffer” than SnPb

- Any weakness at the interface areas is magnified
 - ENIG black pad problems show up more often
 - SnNi intermetallic brittle fractures more common
 - Dissolution of interface materials changes the alloy microstructure
 - Microvoid (kirkendall) problems in the Cu_3Sn intermetallic (that happen on both SAC and SnPb) will result in greater numbers of actual failures with SAC than with SnPb
 - Drop/Shock performance is much less with SAC (405) compared to SnPb
 - The Bare board laminate can be a limiting factor (Pad Cratering)



Kirkendall Voiding defects (when they occur) (also exist in SnPb solder joints) can be catastrophic in SAC solder joints

Example: Left

After 40 days at 125°C, voiding entirely separates the solder joint from the substrate

- Shown to be a significant problem at 70°C also

Mechanical shock and vibration performance greatly compromised.

What Does all this Mean to Reliability and Reliability Predictions?

SAC \neq SnPb - and trying to “shoehorn” SAC into a SnPb model is doomed to fail

We must better understand the failure mechanisms associated with SAC thermal cycling and the factors that influence them.

Any constitutive relations that are developed must account for SAC microstructure

- Worst case rather than general/bulk case

We must “control” the SAC microstructure

- Solder composition (Alloy and effects of interfaces/component metallizations)
 - One alloy would be “nice” - but which one?!
- Temperature affects on microstructure (nucleation, undercooling, etc.)

These are particularly problematic to many Hi-Rel products which are
Thermally Challenging (BTU) Assemblies!

Other Issues: Component Temperature Sensitivity

Certain families of parts are currently known problematic to the high temperatures required for Pb-free soldering. Examples:

- Aluminum Capacitors - Severe Temperature Restrictions
 - Failure to meet results in dryout **IN THE FIELD!** Not likely to be seen in testing.
- Film Capacitors - significant temperature restrictions. (Swelling/"usually" immediate failure)
- Ceramic Capacitors - cooldown rate limitations (not major) - if exceeded, caps will crack and become a field reliability concern.
- Polymer (conformal coated) Tantalum Caps (not the molded type) - venting problem and field failure
- Electromechanical Relays - **performance degradation**, seal "blowout".
- Double-layer Carbon special capacitors - Severe Temp restrictions (completely unusable on Pb-free assembly)
- Fuses, Crystals and Oscillators - time limits at temperature. If exceeded - performance shifts probable (**not likely to find in Functional Test**)
- Some Plastic Package Inductors - time limits at temperature.
- Many large FCBGAs - Can meet the initial J-STD-20C temperature limits, but have rework temperature restrictions (**may not be truly reworkable**). Device specific and must read the fine print on the manufacturer's data.

All of this means "old" designs can't migrate to Pb-free without redesigns even IF all the reliability issues were solved today!

High Rel systems often take 2-3 years and \$50-100 MILLION to develop - then sell for 10+ years and have field lives exceeding 20 years after that.

→Need a long term solution for SnPb BGA availability!

Other Issues related to Pb-free: Industrial/Battelle Class 3 Environment

Board Finishes:

- ENIG, OSP, and Immersion Silver ALL are subject to corrosion in Battelle Class 3 environments (creep corrosion and/or fiber assisted electrochemical migration, blistering/peeling of conductive corrosion products, etc.)
- Only SnPb HASL and Immersion Sn survive this environment
 - SnPb HASL is not Pb-free
 - Immersion Tin has poor solderability performance in Pb-free assembly (and whisker concerns)
- SnCu HASL - has not been tested for this issue but...
 - Greatly undesirable (we don't want this!)
 - Additional severe thermal shock to PWB
 - Same issues with Non-flat pads as SnPb HASL
 - Extremely limited availability
 - Tin Whisker Risk – worse than Immersion Sn
 - Cu dissolution
 - Process Control at fabricator
 - Etc.

NO PATH Forward at this Time!

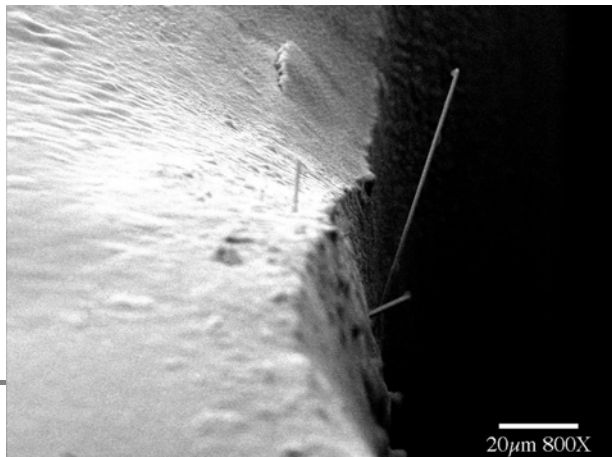
Process Related Reliability Issues (To be covered more completely by Celestica) and Tin Whiskers

Process Related Reliability Issues:

- Cu Dissolution
 - Particularly problematic in Through Hole solder fountain rework
- Rework of BGAs
 - Not only the temperature restrictions of the packages (previously covered)
 - Adjacent component “secondary” reflow
 - BTU boards problematic
 - Can’t space components far enough apart

Tin Whiskers

- This won’t stop us from going Pb-free - as we already have Tin Whisker concerns when soldering with SnPb. However, there are cases where the tin whisker risk may be greater with Pb-free soldering.



70 um whisker, growing from a solder wetted area of a SAC solder joint

Summary

We need a valid model for SAC solder joint reliability

We can't use the SnPb model since SAC can be worse

- High Stress/Strain components are particularly problematic

Unlike SnPb, SAC Properties change with Alloy, Time, Temperature, Crystallography

- We have much to learn here
- Changes identified make much of existing data questionable as to its usefulness

Proliferation of Pb-free Alloys is complicating moving forward

Anisotropic nature of Sn (and SAC) greatly complicates modeling activity

SAC stiffness makes intermetallic interface issues more of a concern than with SnPb

Microstructure of SAC affects reliability

- Process and materials affect microstructure

Component Temperature Sensitivity is a significant issue for "BTU" PCB's

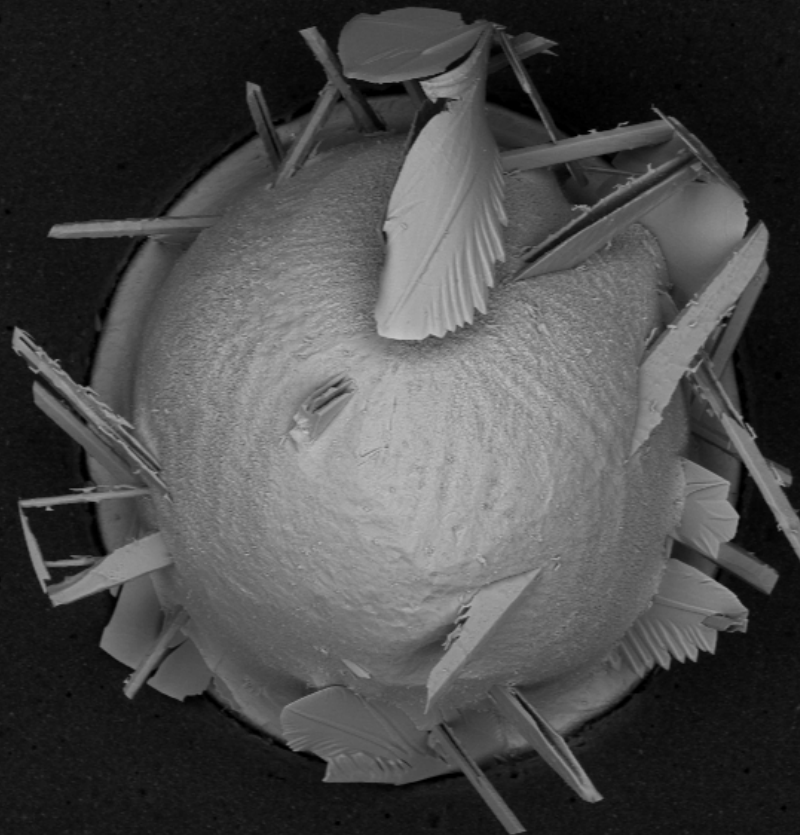
No PCB Finish path forward for Battelle Class 3 environments

Significant remaining Process related issues for "BTU" PCB's

We are working towards a Pb-free solution for High Reliability Products, but it is not a simple exercise to ensure the needed reliability. Even when we resolve the issues, there will remain a (diminishing) long term requirement for SnPb BGA's.

Parting Picture to Think About...

Picture of SAC solder ball with much of the tin etched away - leaving the various CuSn and SnAg intermetallics



30µm
┌───┐

Mag = 350 X

NOKIA
Dallas Analytical Lab

Date : 3 Mar 2004
Detector = QBSD

Backup Slide on Mixed Technology

What About Mix Technologies?

We have worked on multiple studies with consortium, and reviewed lots of suppliers test data

Lot of conflicting information

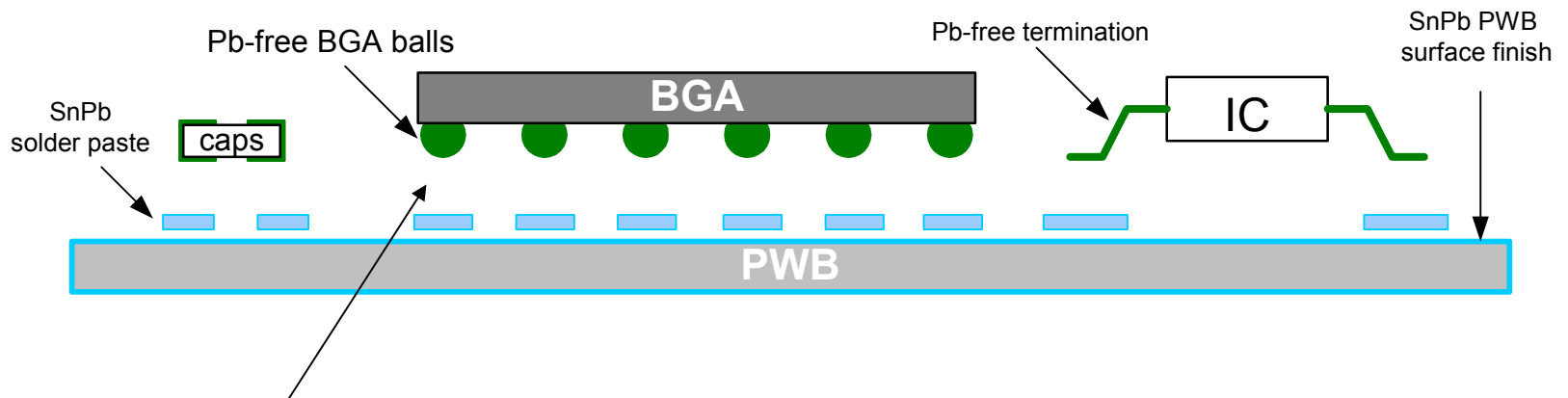
Some “good”, some “bad”

Even the “good” generally has outliers when sample sizes are large

Still not too well understand, and too many variables

It represents high risk in most of the high complexity products

Not recommended or acceptable by many OEMs



This is mix technology. Mainly referred to mixing Pb-free BGA with SnPb process.