LEAD FREE WAVE SOLDERING

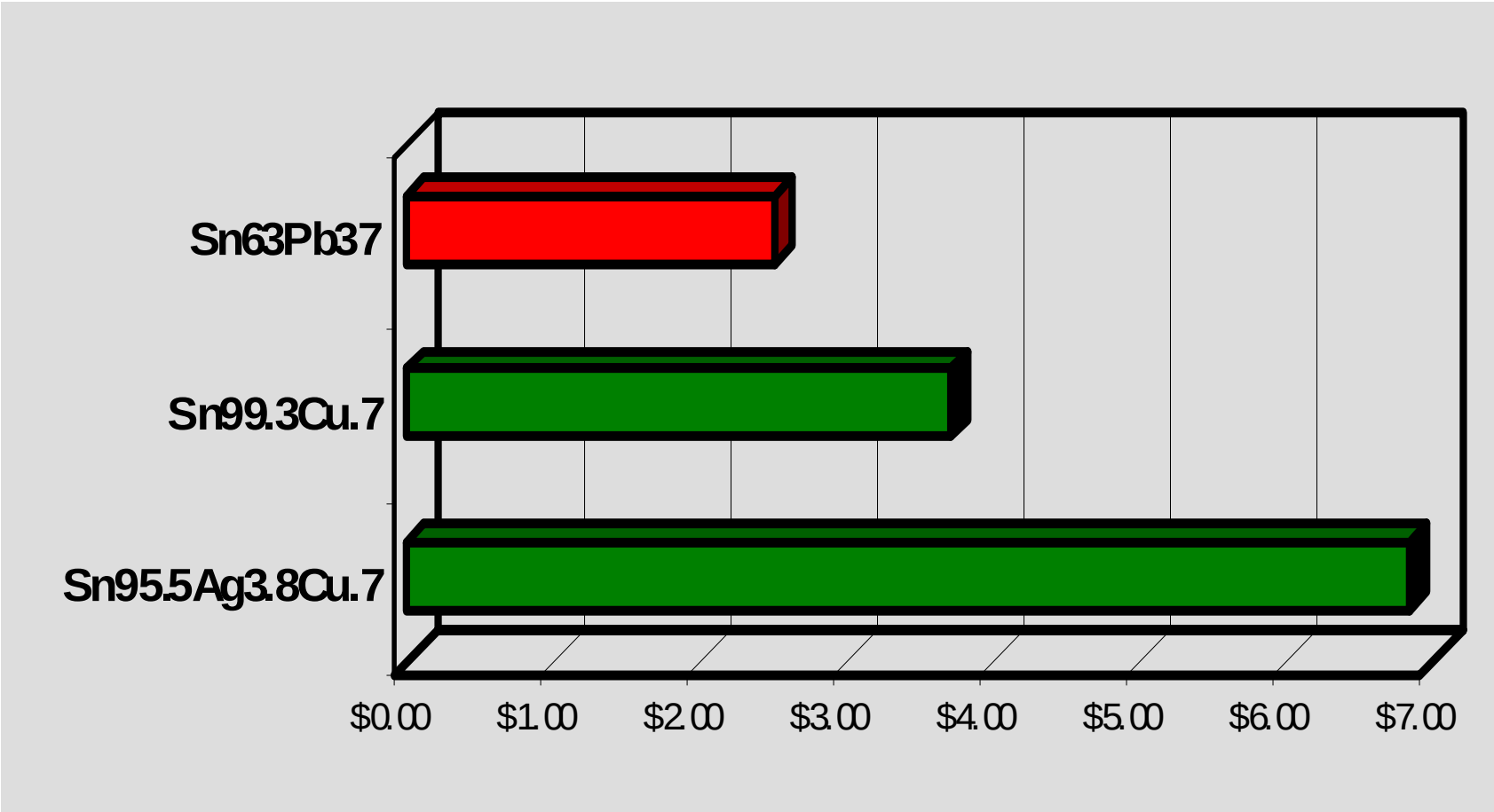
Lead in Soldering

- Diluent for tin which -
  - Reduces surface tension
  - Reduces the melting temperature
  - Reduces the cost
- Low environmental impact mining
- Low energy smelting
- Known toxic element
  - Processing controls
  - Closed loop applications desirable

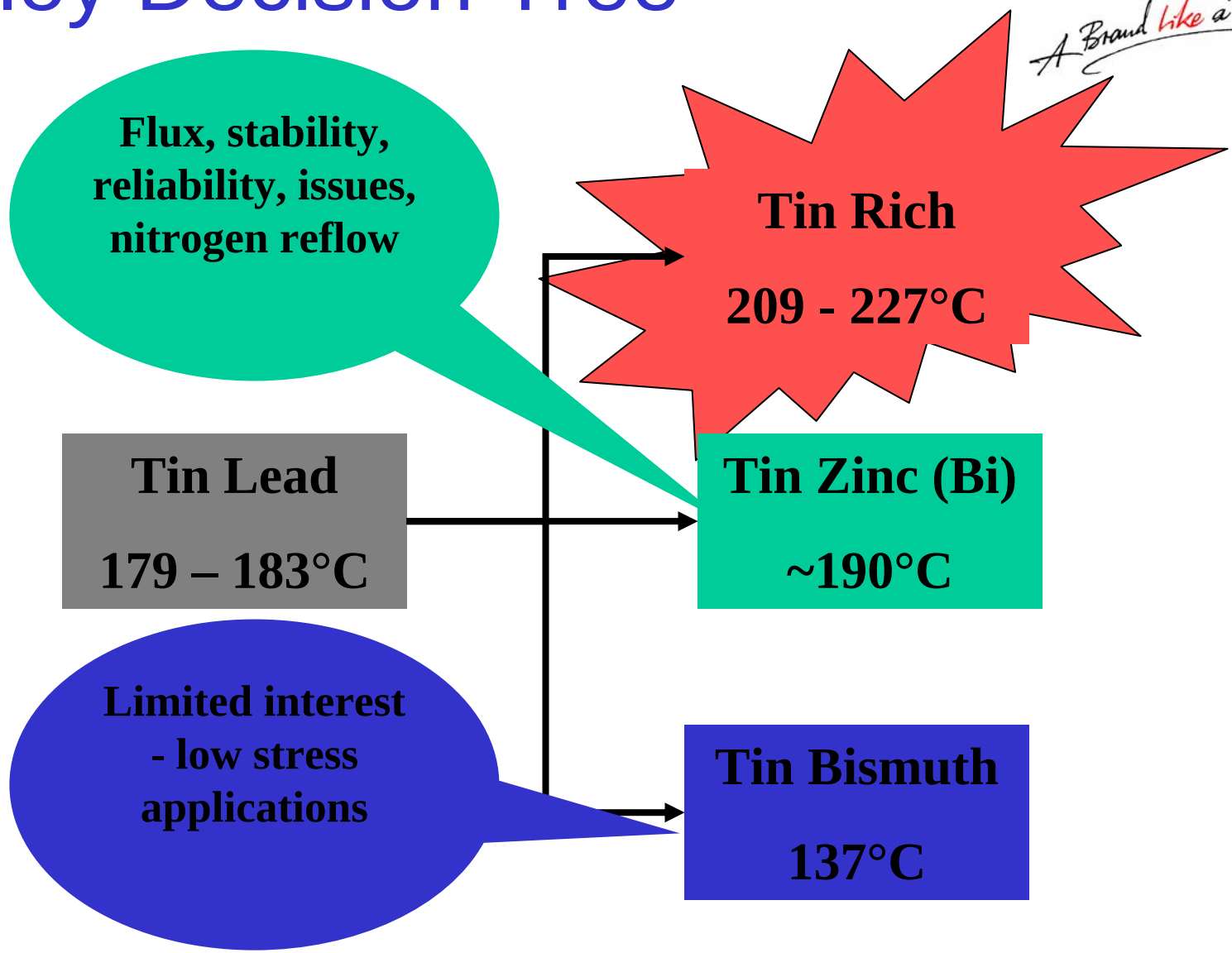
Price & Availability of Alternatives

- Current availability
- Current price
- Capability to support extra market
- OK
  - Tin, copper, zinc, antimony, silver, bismuth (minor component)
- Not capable
  - Indium

Relative costs of selected alloys



Alloy Decision Tree



Low Melting Temperature Option

Tin Bismuth - Sn43Bi

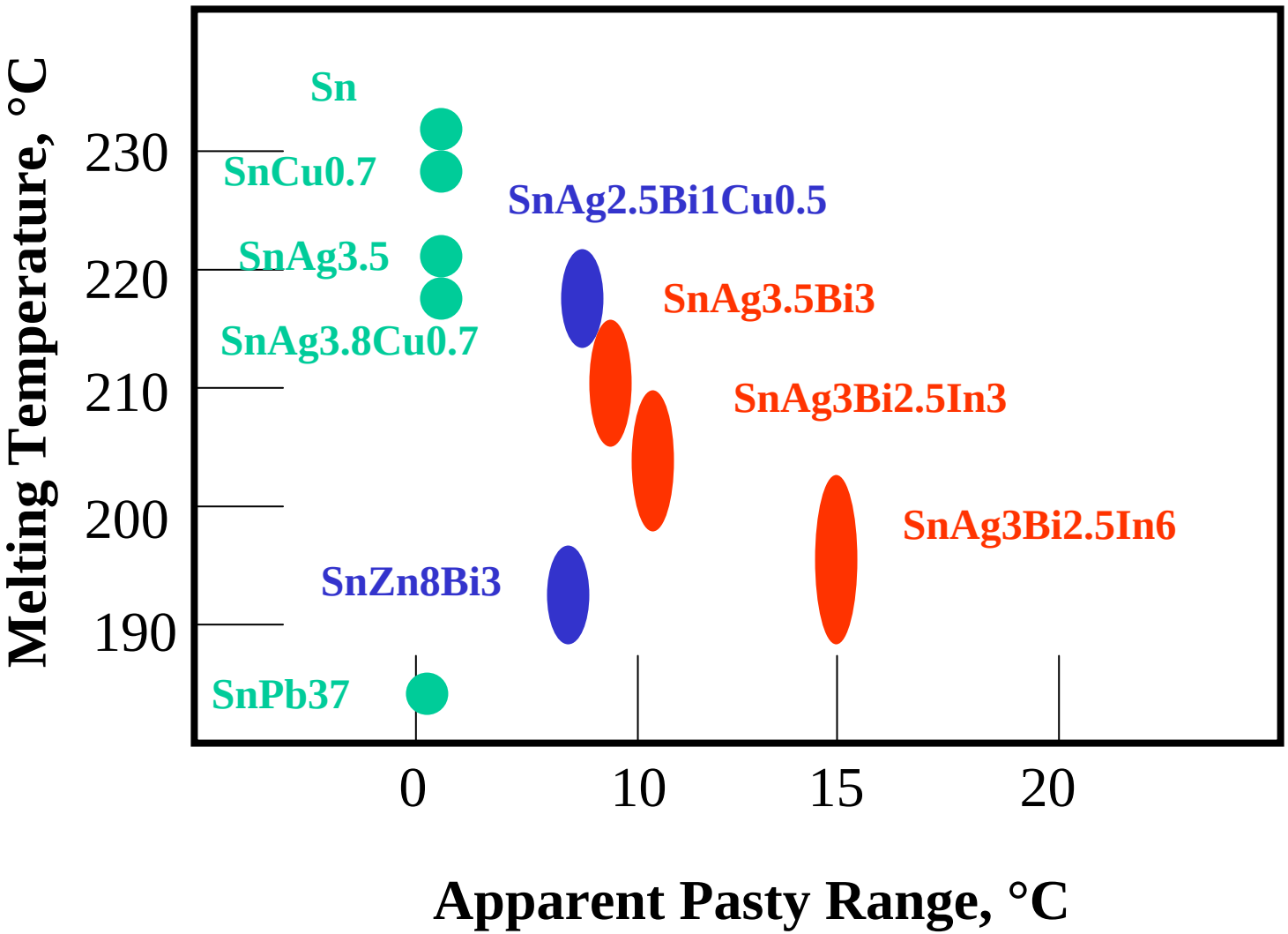
- Eutectic
  - melting temperature 137°C
- Limited wetting performance
  - difficult to get good flux activity at lower reflow temperatures
- Good joint strength & reliability
  - limited upper temperature
  - very sensitive to Pb contamination

Higher Melting Temperature Options

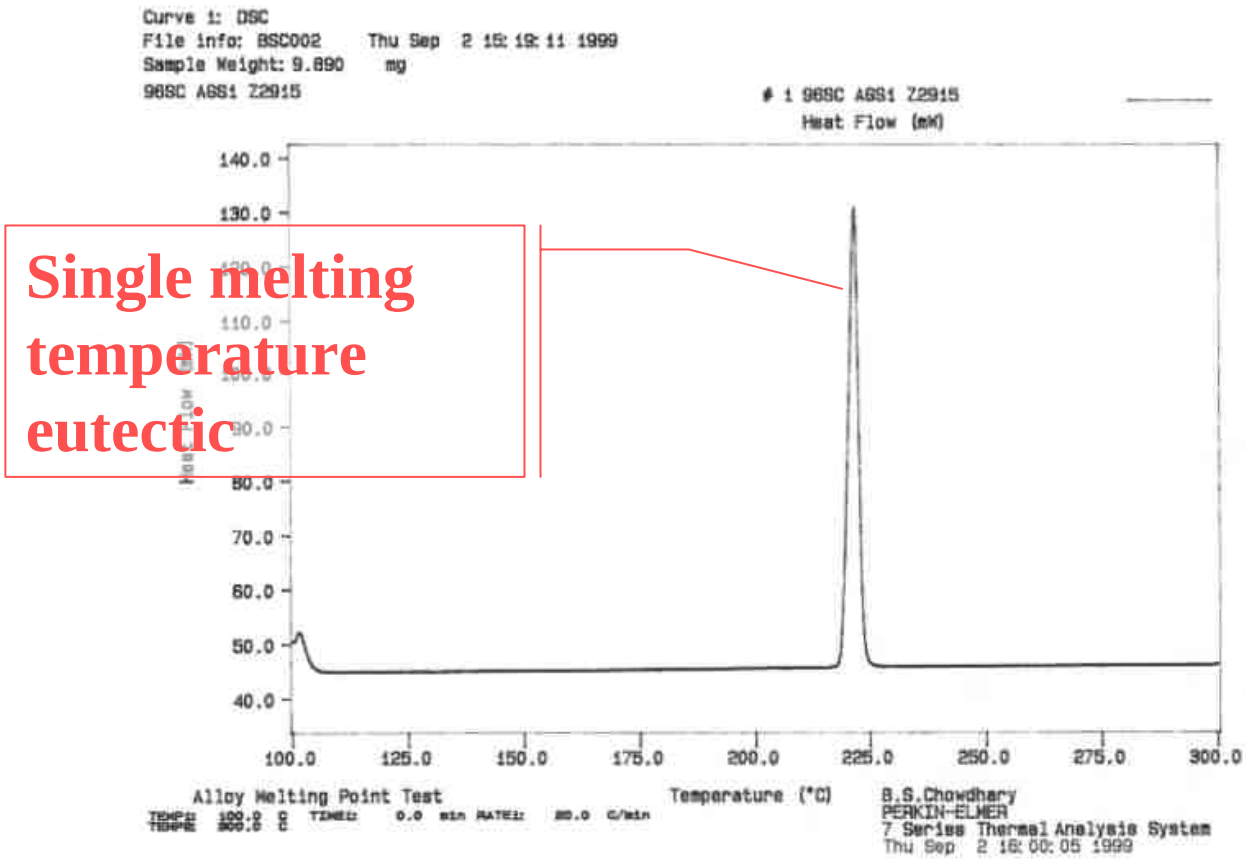
Tin Rich Eutectics

- Copper eutectic
  - low cost diluent
- Silver eutectic
  - high cost diluent
- Tin/Silver/Copper eutectic
  - lowest melting temperature eutectic

Melting temperature vs melting range

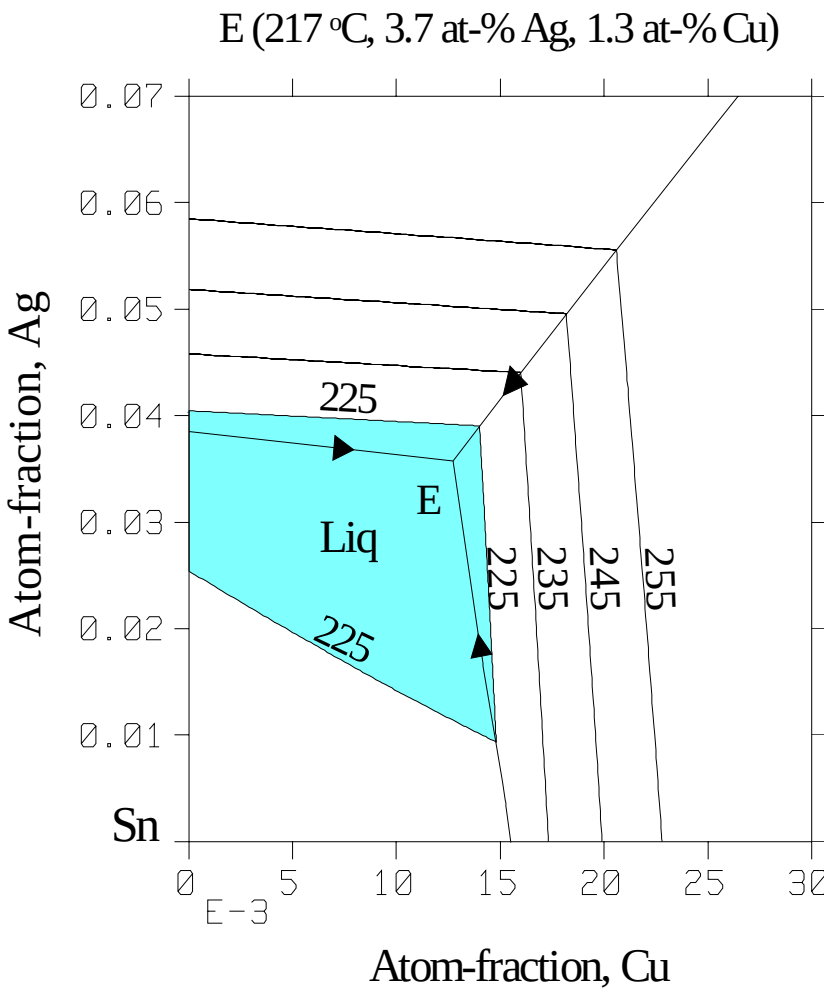


DSC curve SnAg3.8Cu0.7



Single melting temperature eutectic

Tin-Silver-Copper Liquidus

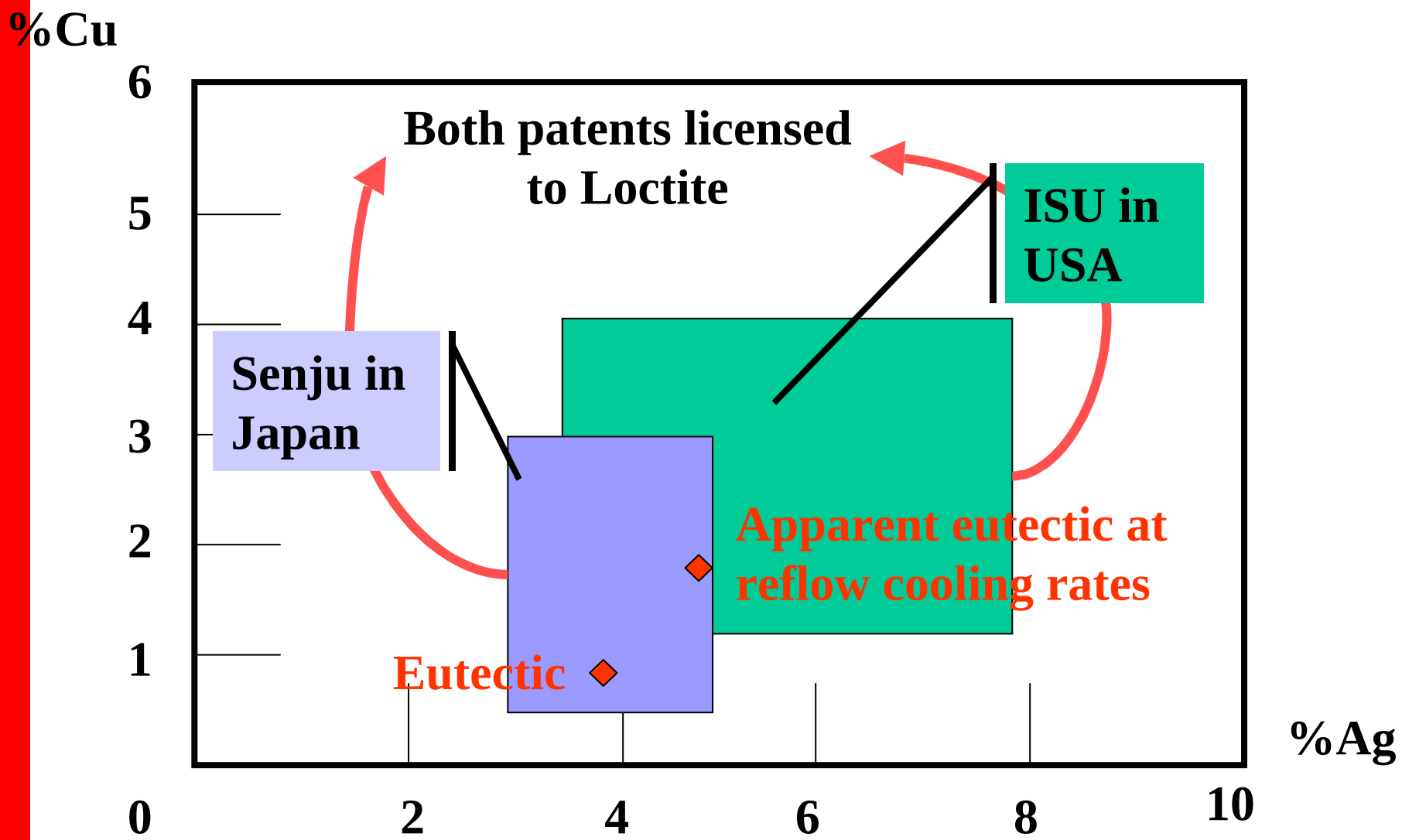


- Thermodynamically calculated
- Equilibrium eutectic at 217°C SnAg3.4Cu0.7 but microstructure is eutectic + Sn dendrites
- Fully eutectic microstructure needs higher Ag and Cu: SnAg4.7Cu1.7

Alloy Patent Considerations

- The scope and validity of patents can only be established when the owner defends them.
- Loctite wants to avoid potential conflicts for customers
  - negotiated licenses that allows our customers to use our alloys and sell their products worldwide

Lead free Alloy Patents in Japan and USA



The Significance of Alloy Composition

- Control of the ***initial*** composition
  - wave solder bath
  - solder powder
  - solder wire
- Composition of the solder ***in process*** & ***in the final joint***
  - sources of contamination
  - effects of contamination

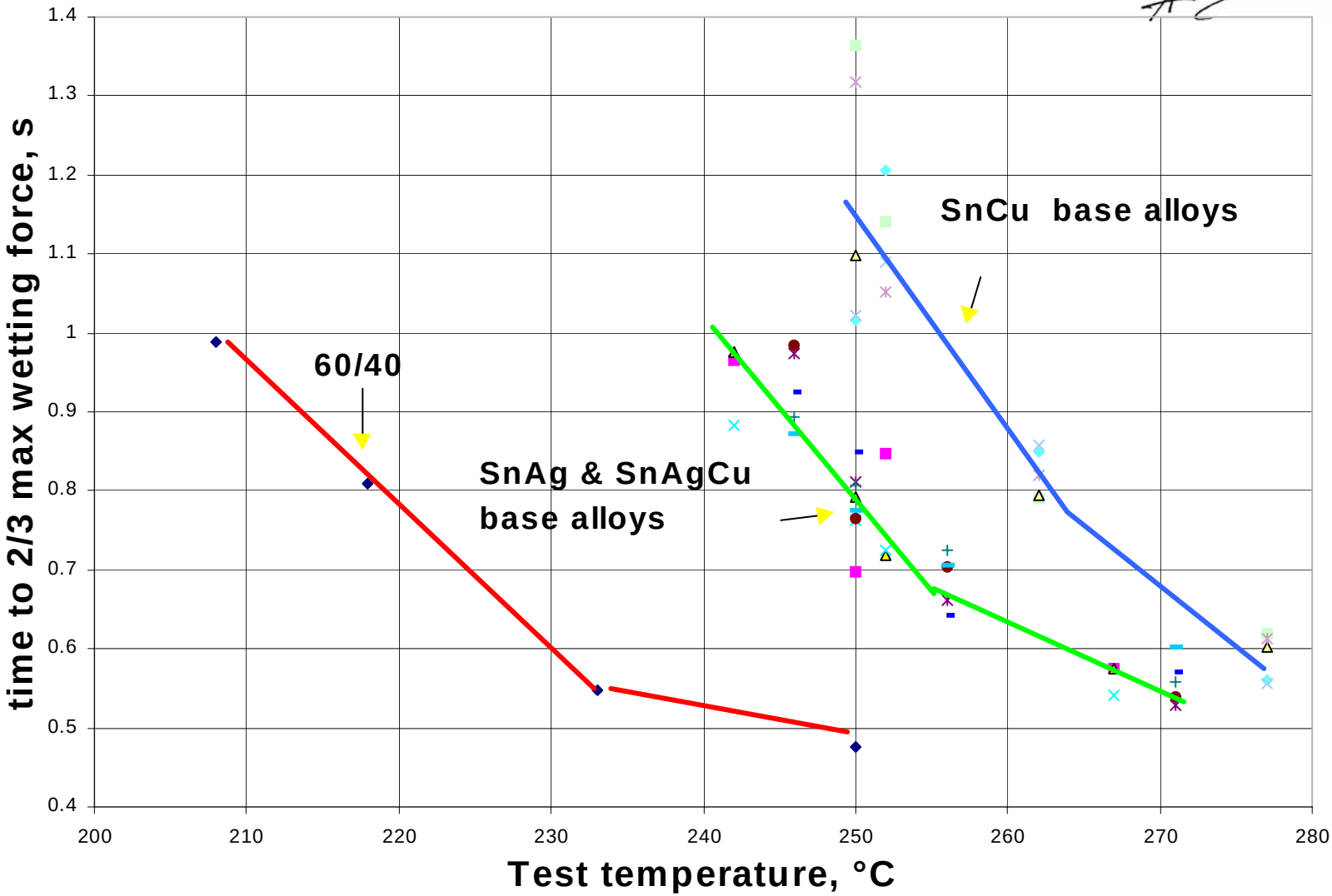
Loctite Multicore Alloy Specifications, %

Metal	96SC	97SC	Typical
Ag	3.6 – 4.0	2.8 – 3.2	-
Cu	0.6 – 0.8	0.4 – 0.6	-
Pb	< 0.1		<0.05
Bi	< 0.05		<0.01
Cd	< 20 ppm		<5 ppm

Pb-free Alloy Wetting Behaviour

- Higher melting temperature
  - expect to need higher soldering temperatures
  - higher soldering temperature increases flux activity
- Wetting Balance Tests
  - quantify the ***wetting rate*** behaviour
- Spread Tests
  - quantify the ***equilibrium wetting*** behaviour

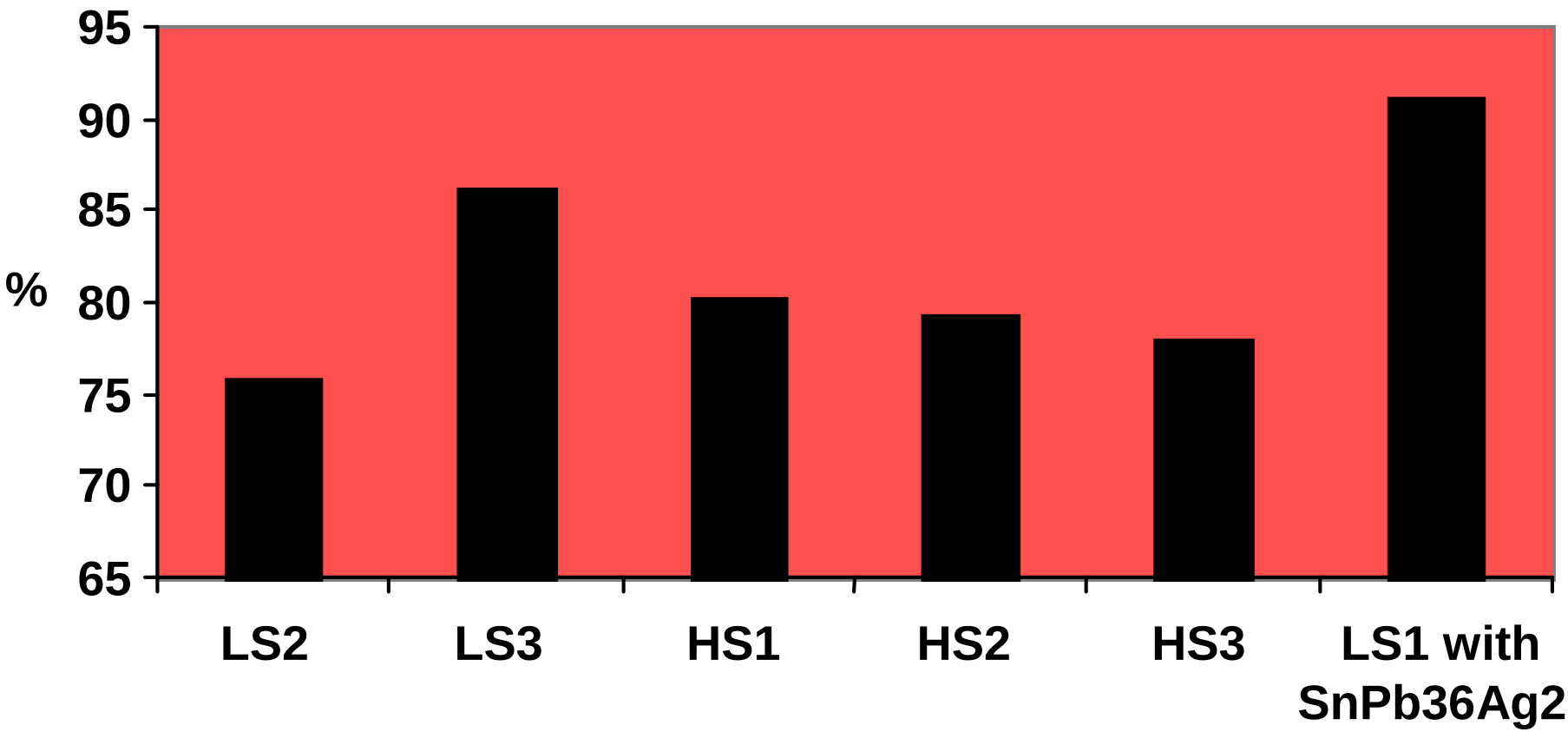
Summary wetting speed vs temp.



Can Wetting Rate be Enhanced?

- Flux activity is the main parameter
- Alloying changes
  - Sb, Bi have been proposed as wetting rate enhancers
  - Observations show the same effect of minor and impurity elements as known for Sn/Pb alloys

Flux Type and Spread on Cu



Effect of Pb-free Alloy Surface Tension

- Tin-rich alloys have a higher surface tension than Sn/Pb
- Pb-free alloy spread and capillary filling should be reduced
  - effect is sensitive to substrate surface finish
  - can be demonstrated by measuring contact angles
    - low values indicate good spread

Alloy Contact Angle vs Substrate

Solder paste contact angles all in the range 20 - 25° for the same flux system

SUBSTRATE	REFLOWED ALLOY PELLET (Sn +)					
	0.5Cu	3.5Ag	3.8Ag0.7Cu	3.5Ag0.5Sb	3.8Ag0.7Cu0.5Sb	37Pb
Cu	42	43	43	41	43	12
Ag	19	26	24	30	33	13
Sn37Pb	19	19	22	20	22	5
Sn0.7Cu	15	11	18	11	10	17
Au over Ni	9	6	10	14	5	4

SnAgCu Alloy Properties

- Lower density than Sn62/63: 7.5g/cm2
- Stable dispersion of intermetallics Ag_3Sn, Cu_6Sn_5 in tin matrix
- Creep strength x4 higher than SN62, Sn63
- Better high temperature strength than Sn62, Sn63 (higher melting point)
- Reliability: conservative view says performance is equal to Sn62/63

Summary on Alloy Selection

- Alloy selection should not be a barrier to Pb-free builds
- The benchmark material is Sn/Ag/Cu eutectic
  - introduce this as the first level change from Sn/Pb
  - look for technical and economic improvements once the process is stable
    - normal process improvement strategy

Wave Soldering Alloy

- Cost of the alloy
  - favours of SnCu0.7
- Process benefits
  - **favours addition of silver**
  - improved wetting
  - reduced temperature
  - reduced leaching from Ag finishes
  - BUT increased machine erosion
    - can be prevented

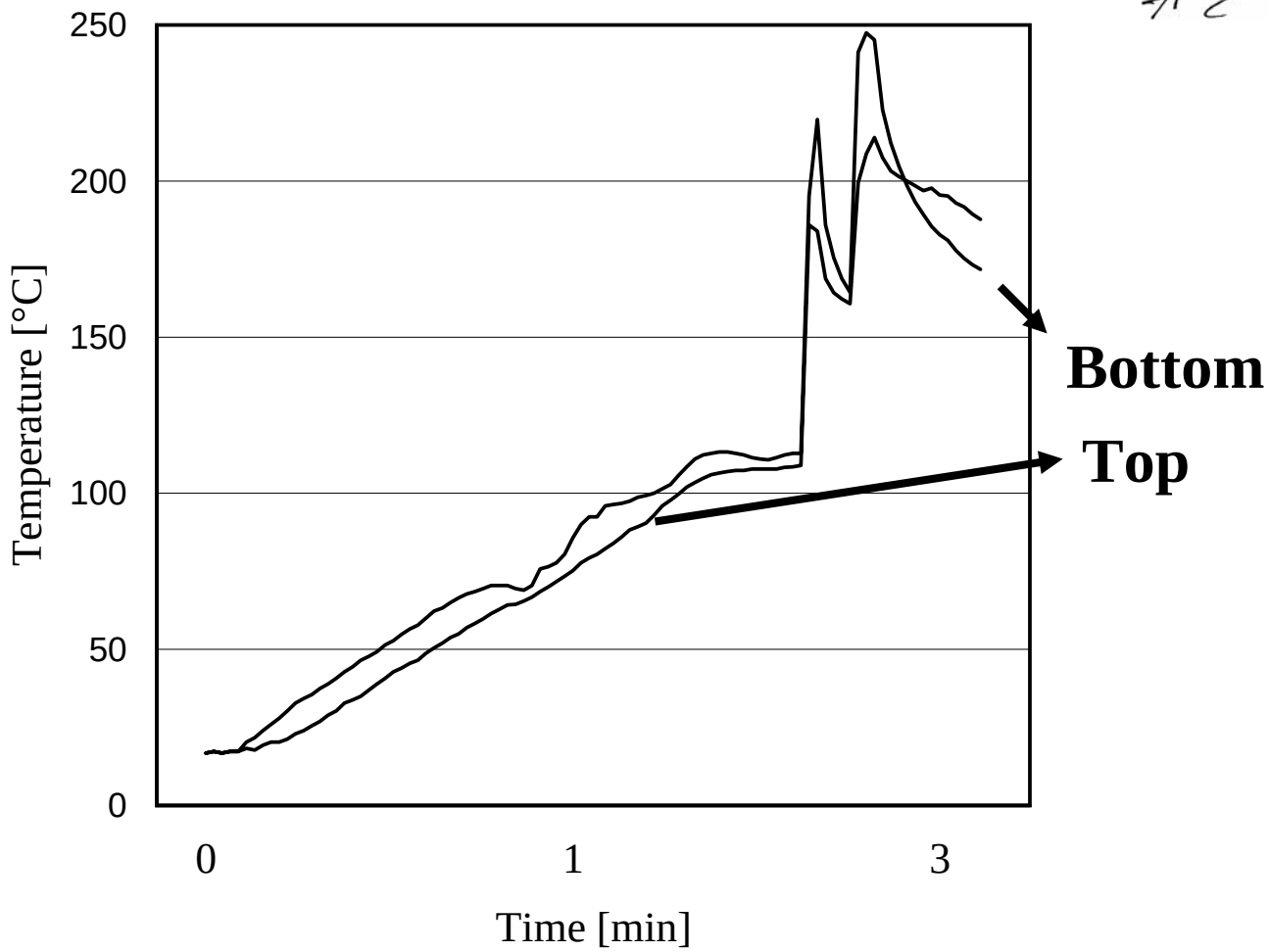
Balance these factors. Look at Total Cost of Ownership

Wave soldering alloy control

Contamination from PCB, components and machine

- Drossing increase?
  - Nitrogen inerting - also improves wetting
- Increased intermetallic - gritty joints?
- Increased bridging?
- Low melting phases
  - fillet lifting

Example Temperature Profile



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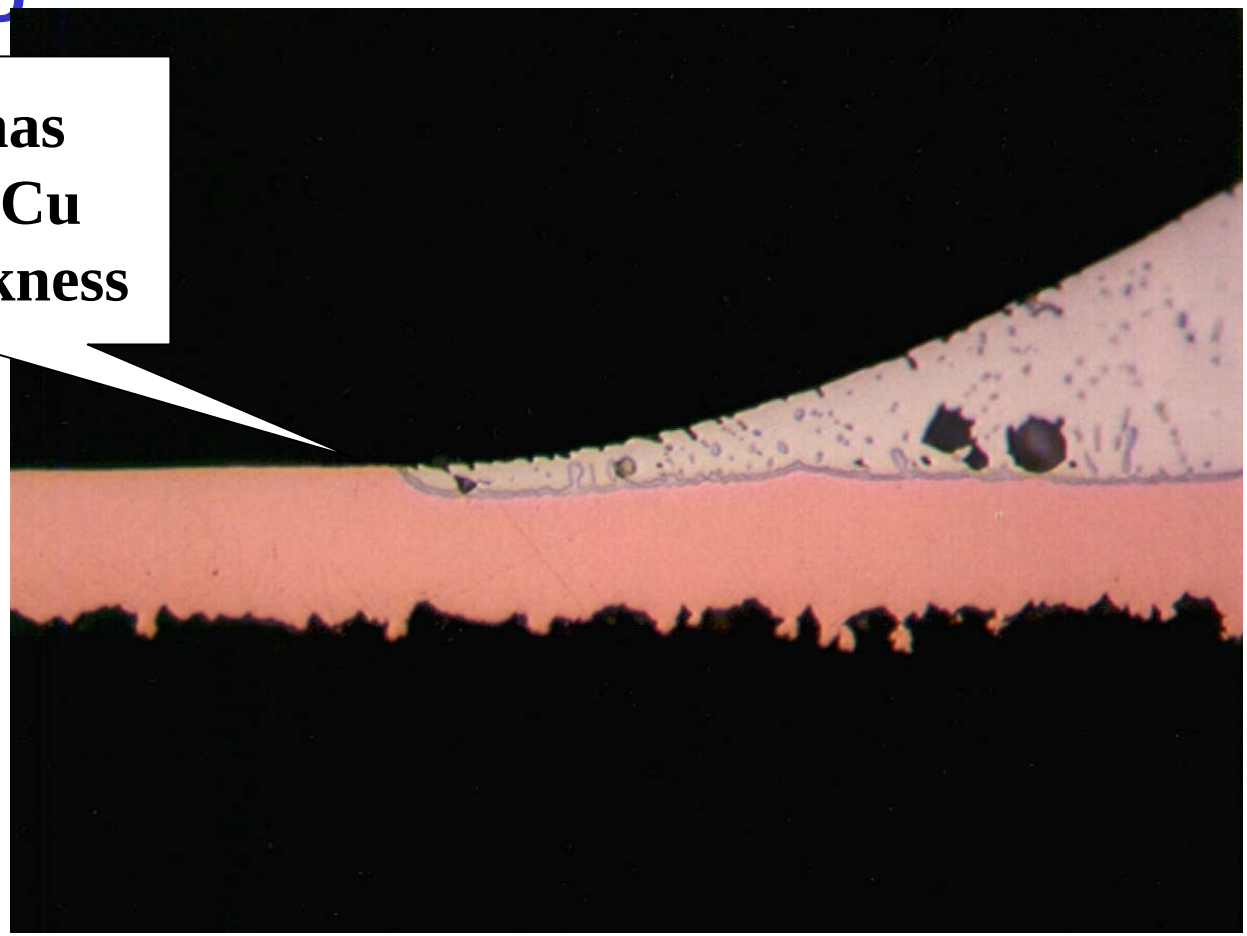
Drossing with Pb-free alloys

Wave soldering temperature higher - creates greater risk of drossing

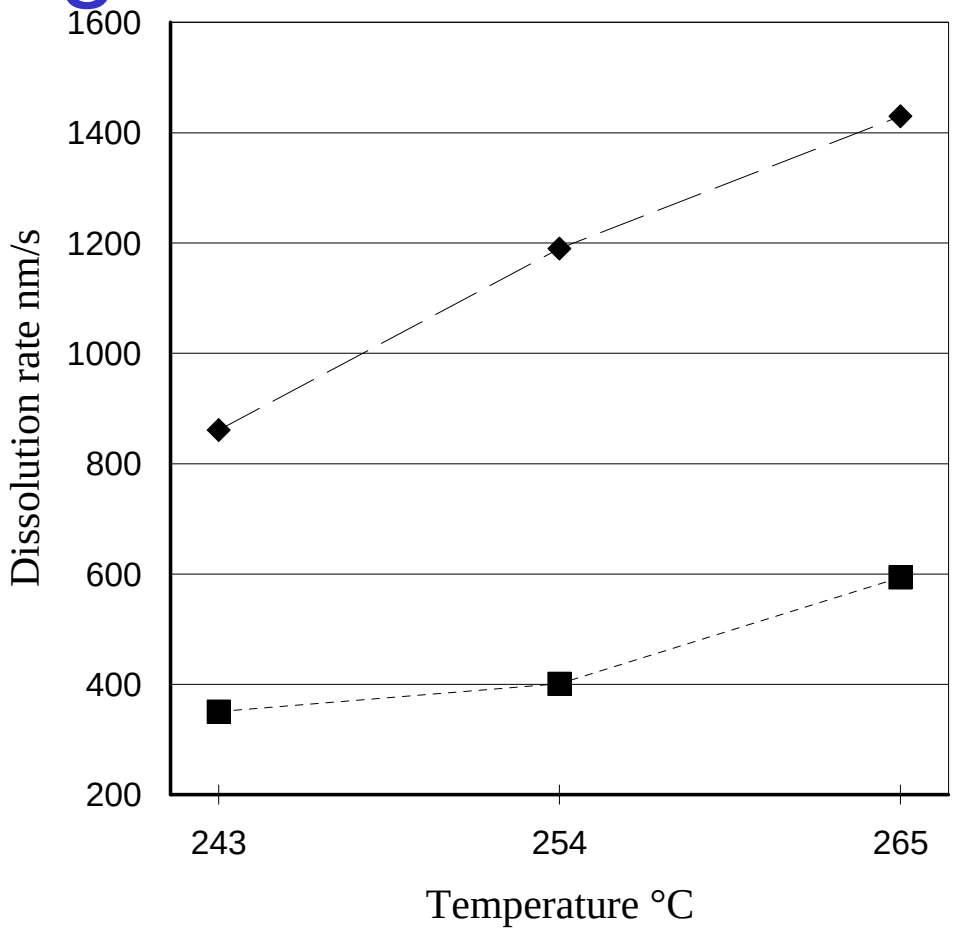
- May drive to use of nitrogen
  - experience shows this is not essential
- Effect of impurities generally greater than for Sn/Pb
- Some impurities experimented with as grain refiners behave as dross promoters as would be expected with Sn/Pb solders
- Addition of P can reduce drossing rates

Dissolution of Cu during Pb-free wave soldering

Solder has reduced Cu track thickness



Cu Dissolution into SnAg3.8Cu0.7



Cu wires immersed in solder

Static

Dynamic

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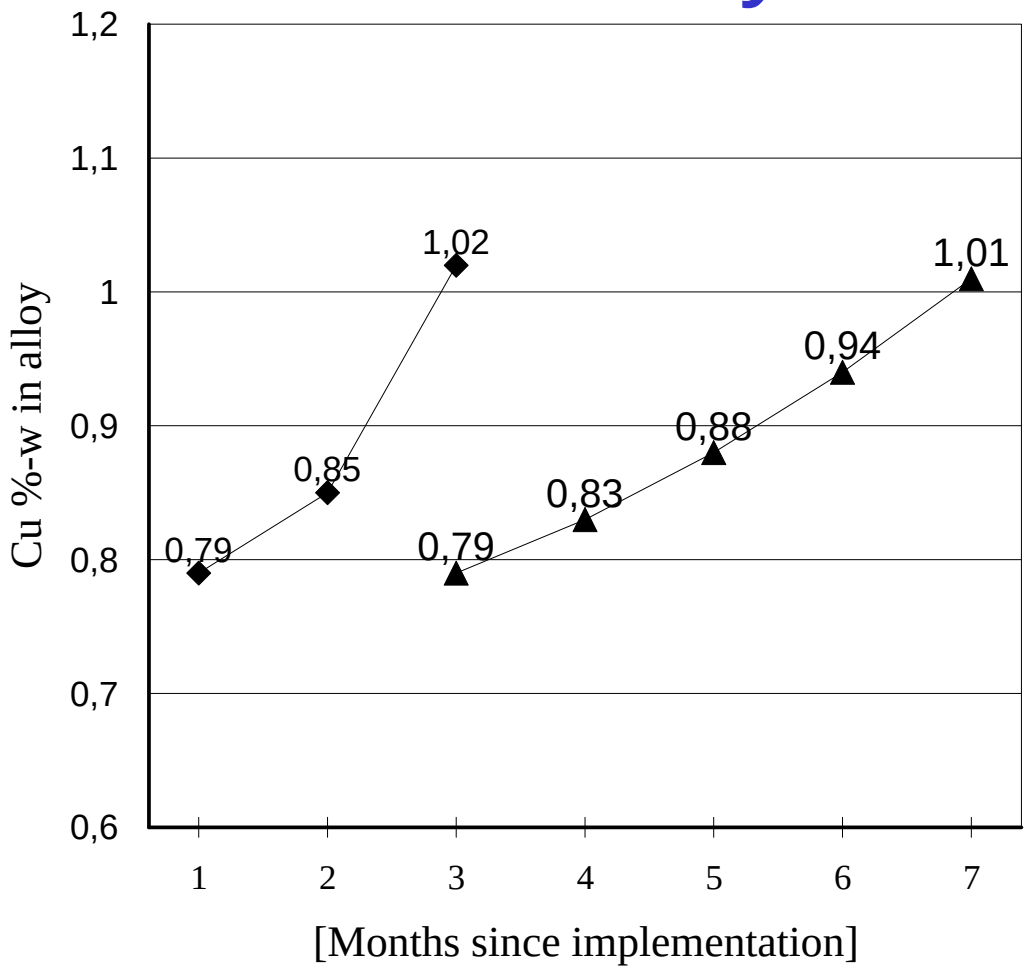
SnAg3.8Cu0.7 Bath Contamination by Cu



- **Cu build up came from the PCB**
- **>1% Cu caused intermetallic particles causing bridging defects**
- **SnAg3.6 added to the bath to dilute the Cu @ 3 & 7 months**

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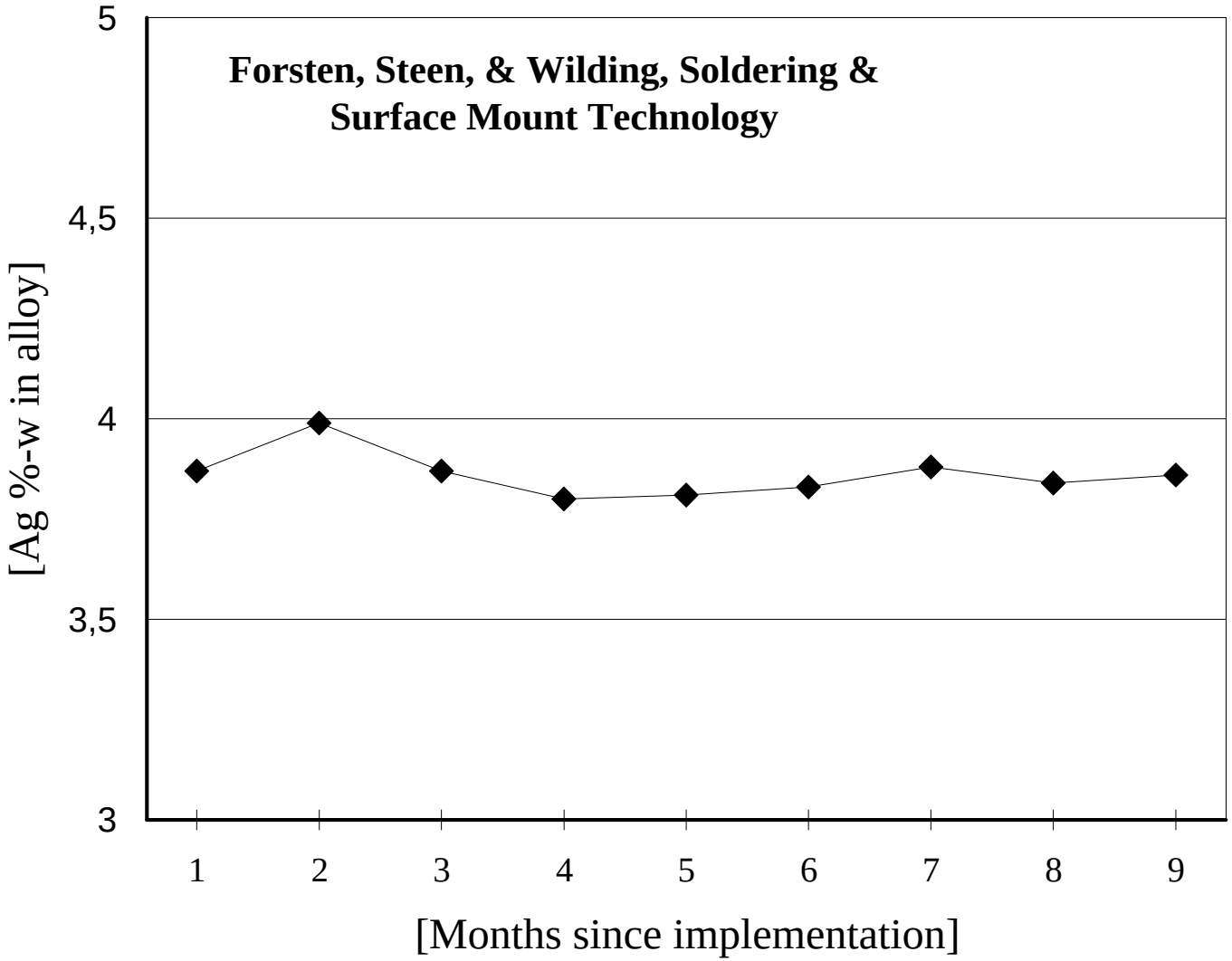
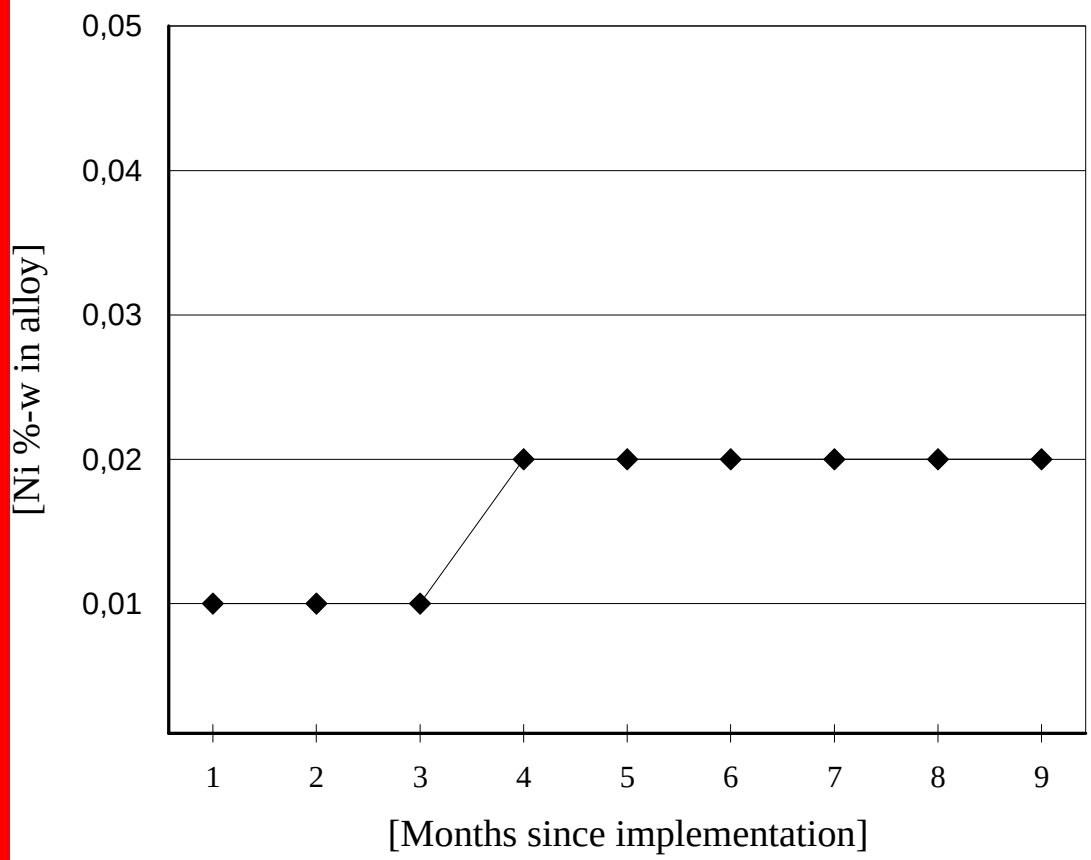
SnAg3.8Cu0.7 Bath Ag Content



- **Ag content stable as expected**
- **Ag finishes not dissolved rapidly into the solder**

SnAg3.8Cu0.7 Bath Contamination by Ni



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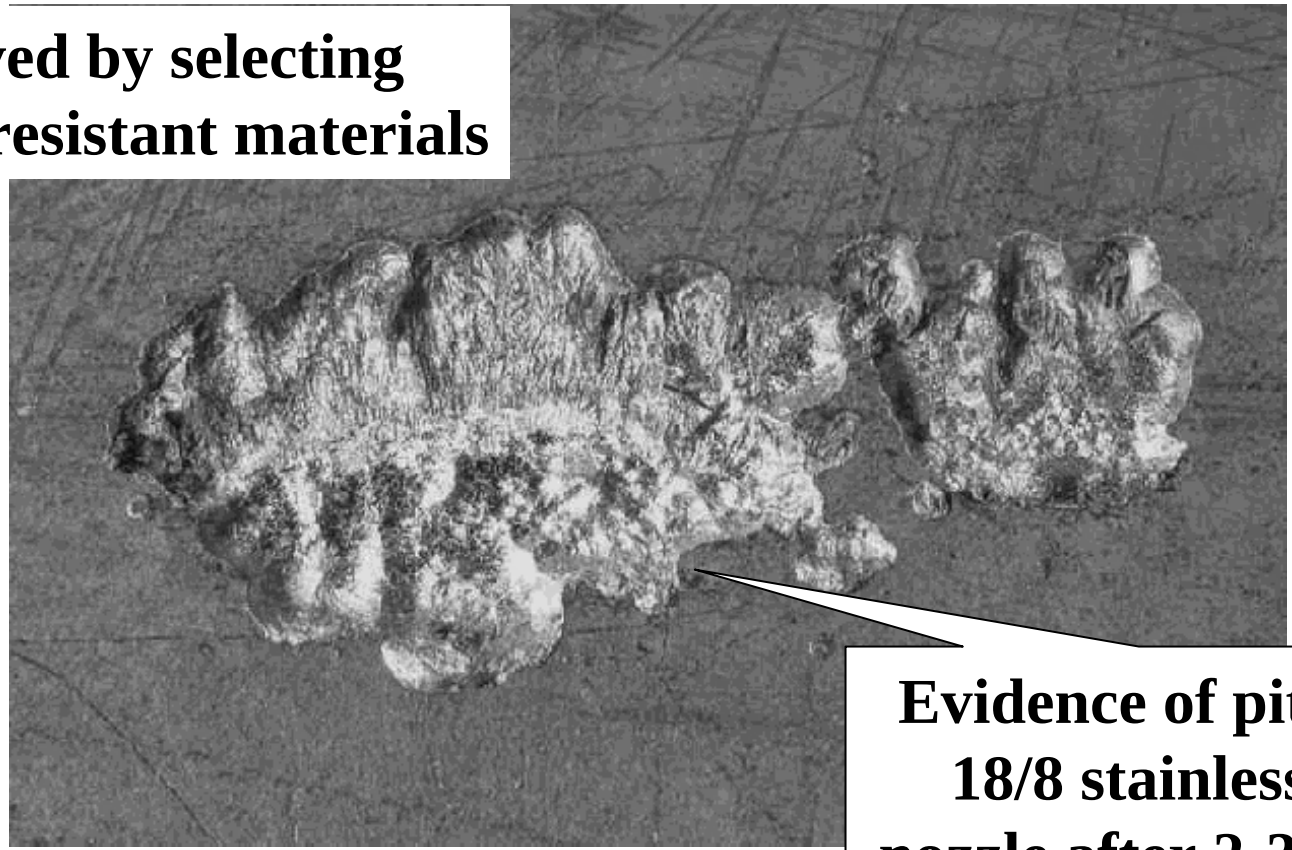
- **Nickel accumulation is a result of dissolution of nozzle and pot materials.**
- **Attack was observed after 2-3 months of operation.**
- **Accumulation has been stopped by fresh solder additions to compensate loss by drossing and as joints.**

Eroded area on nozzle flow guide

Resolved by selecting more resistant materials



Evidence of pitting on 18/8 stainless steel nozzle after 2-3 months production

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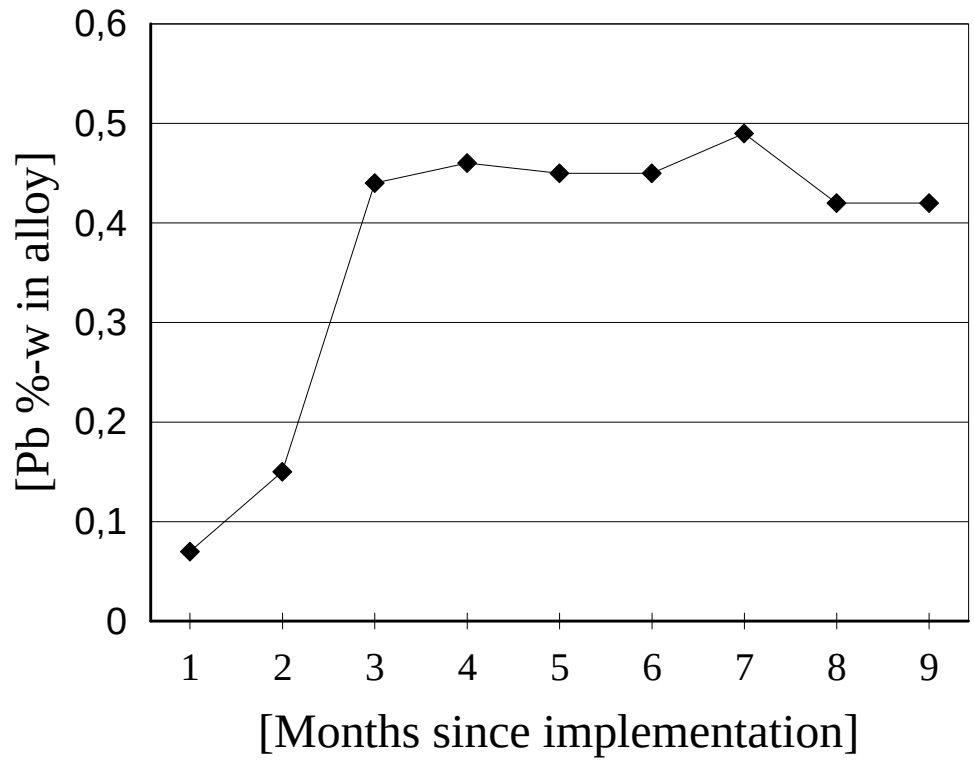
Pb contamination of Solder Bath

- Most processes will bring Pb to the bath for some time into the future
- Major effect is the generation of “fillet lifting” defects on double-sided boards
  - cosmetic
  - no measurable effect on reliability
  - has to be avoided because it is not easily distinguished from other defects that are a reliability hazard

SnAg3.8Cu0.7 Bath Contamination by Pb



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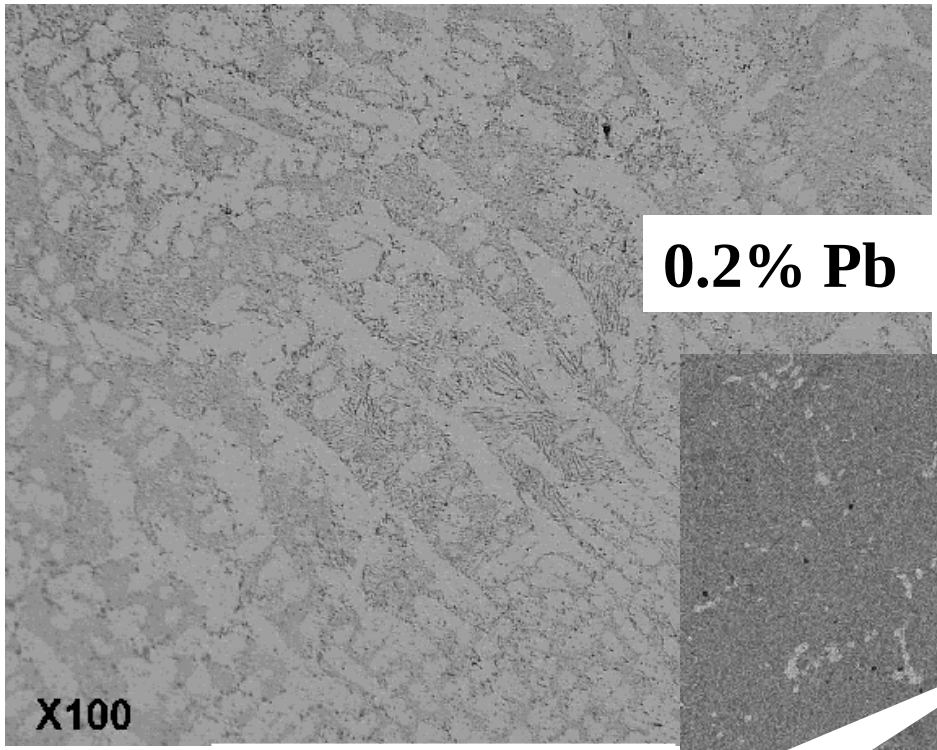
- **50% of all PCBs during the observation period were SnPb HASL plated and some components had SnPb finishes.**
- **50% of boards were lead-free HASL (SnCu0.7) or immersion Gold plated.**

SnAg3.8Cu0.7 Pb Contamination



0.2% Pb

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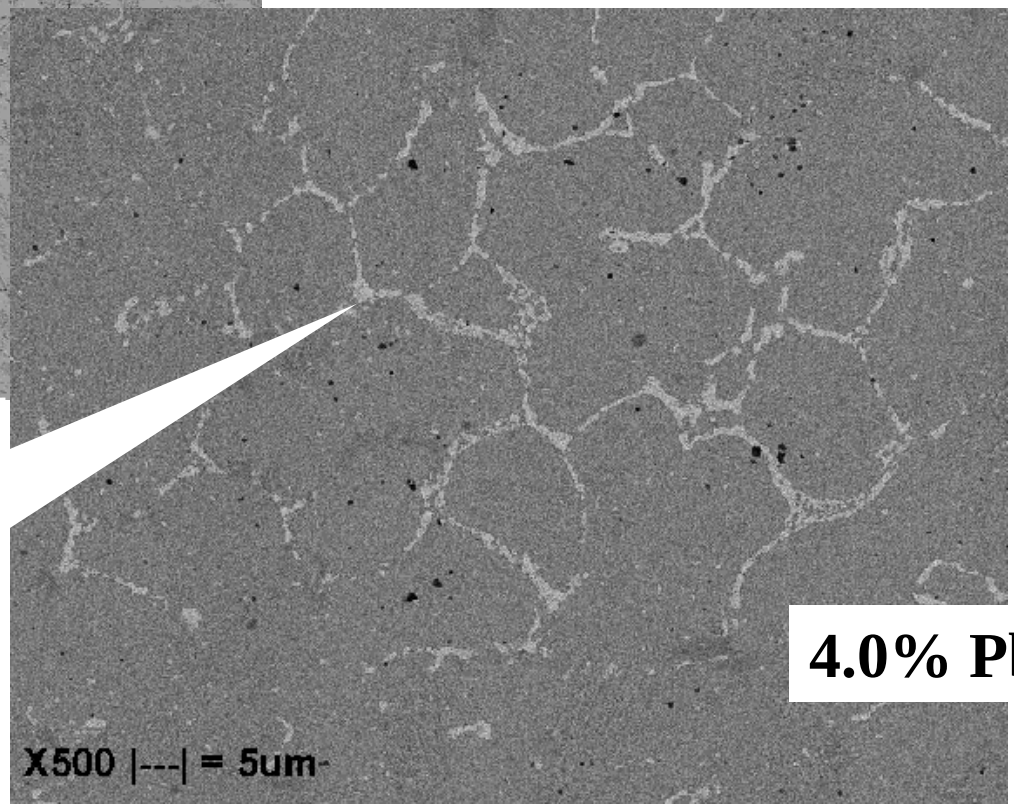
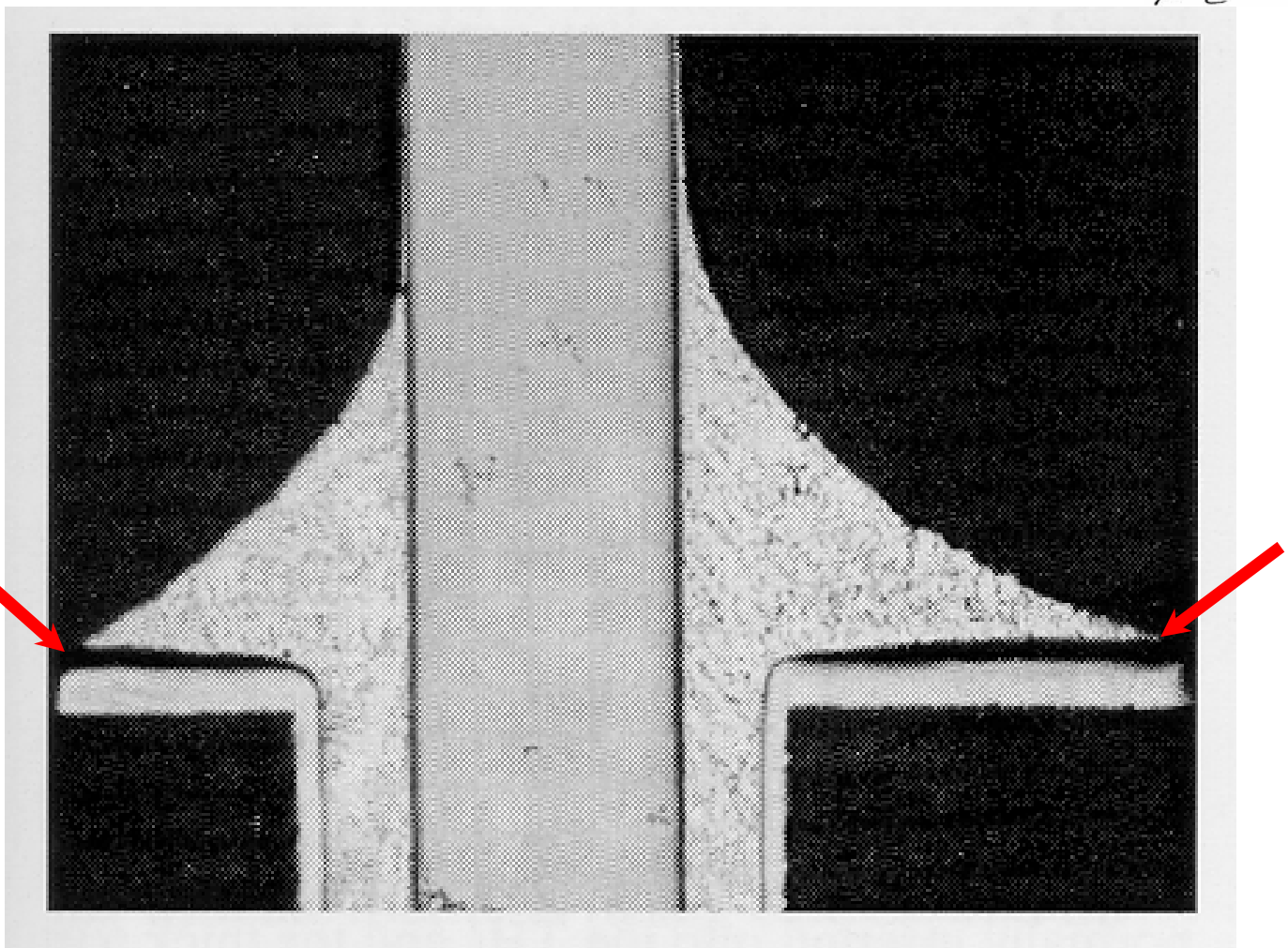
Pb-rich phase, 179°C melting temperature

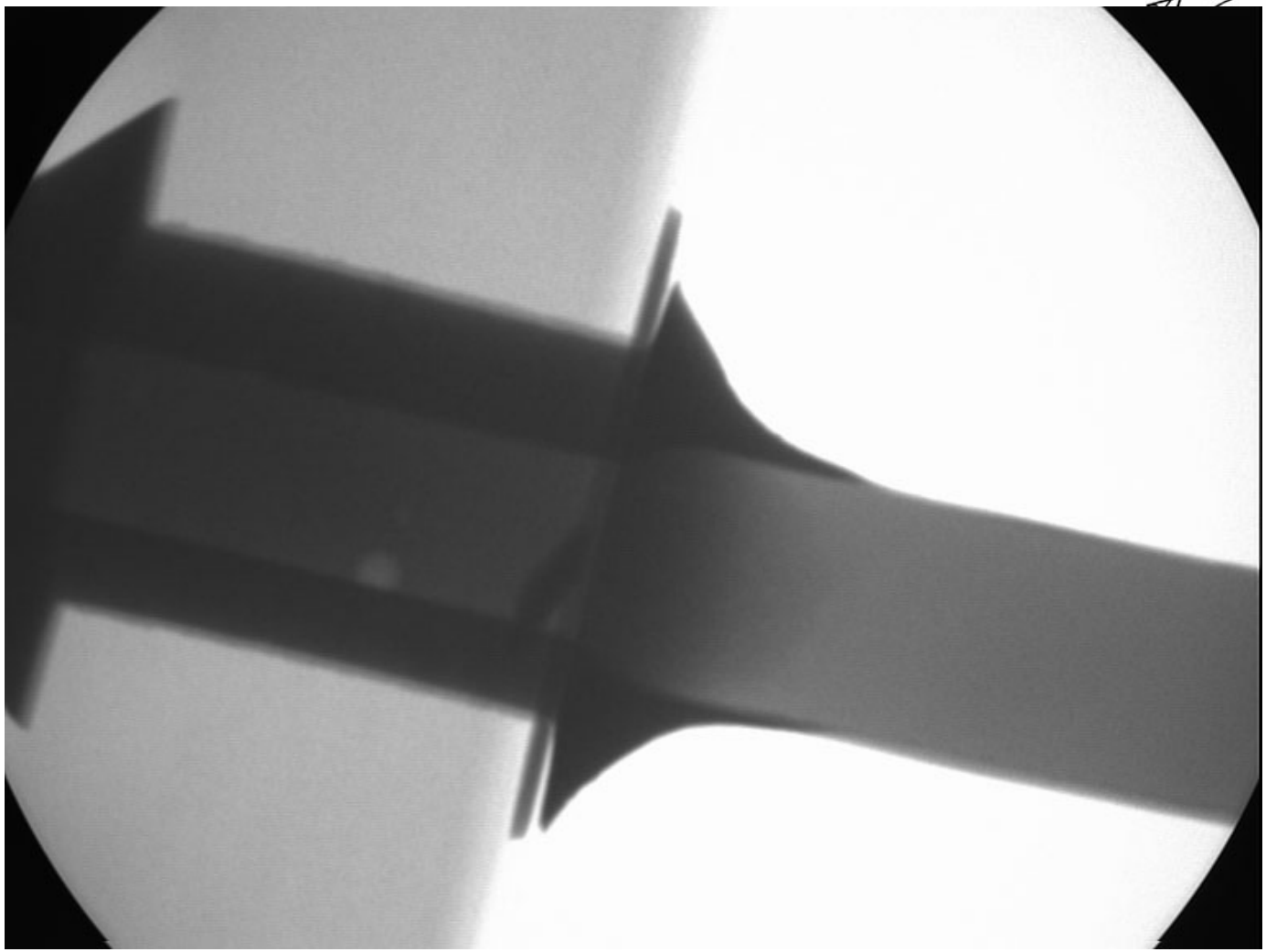


4.0% Pb

Example of “Fillet Lifting”



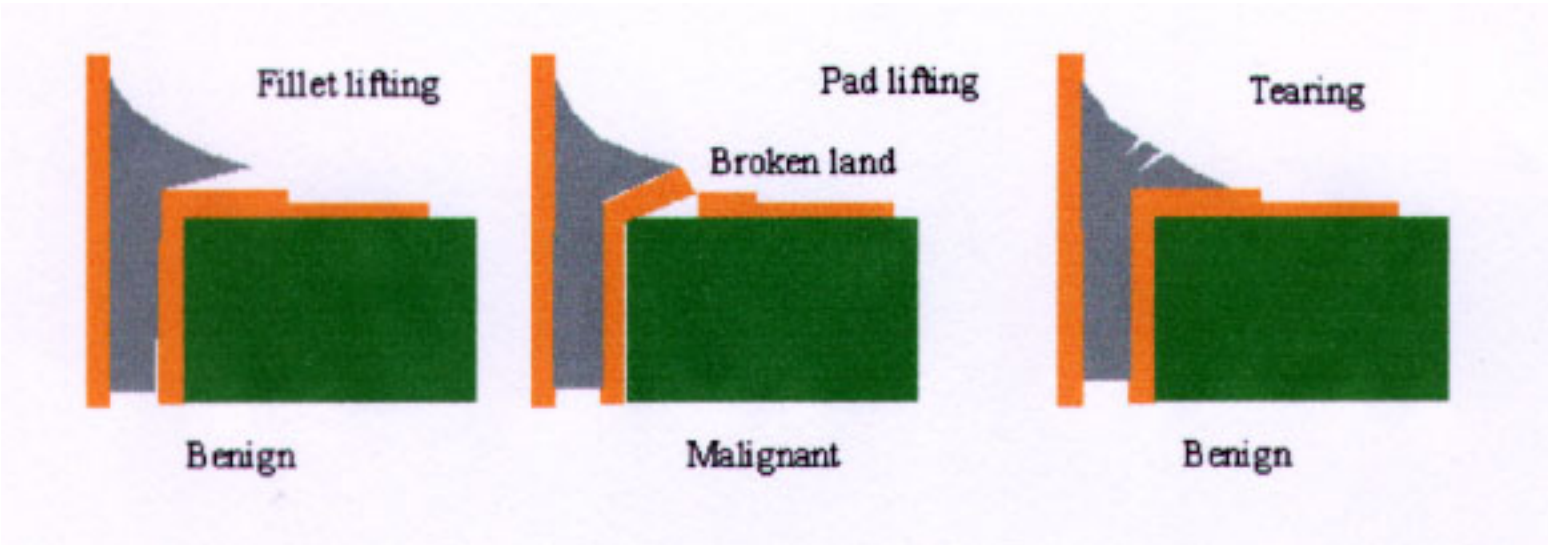
X-Ray image of “Fillet Lifting”



Courtesy - Bob Willis, Electronic Presentation Services

Fillet Lifting

- In general fillet lifting does not affect the strength or reliability of the soldered joint
- Broken lands, however, will cause functional failure



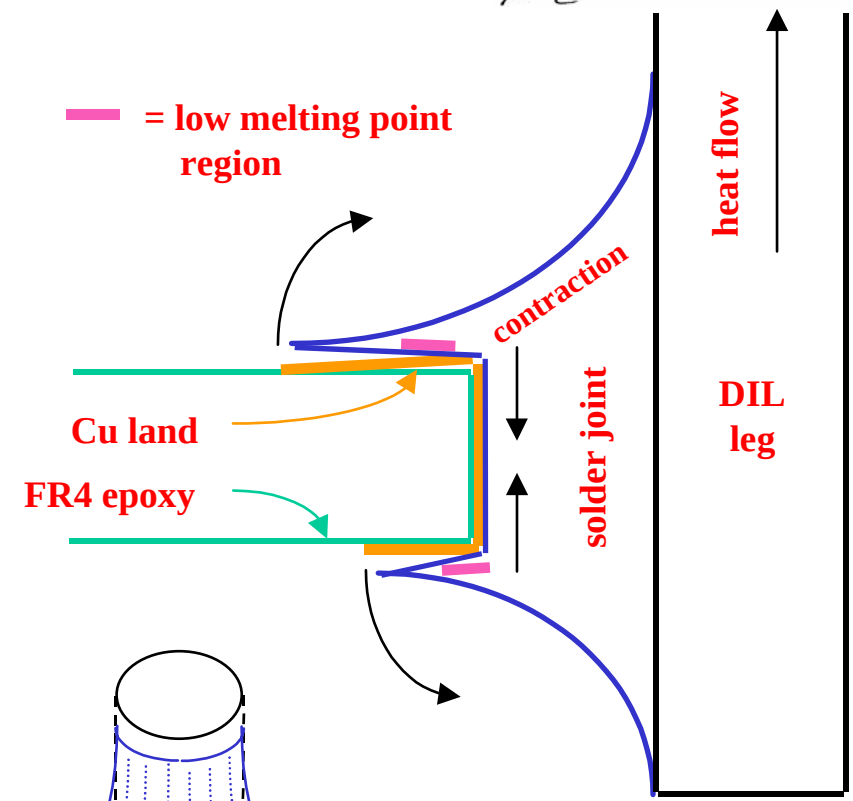
Fillet lifting

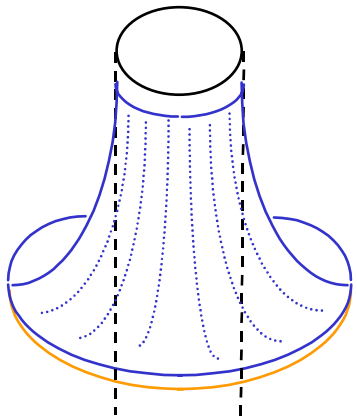
- Occurs when Sn/Pb plated through hole components are Used in conjunction with PB free wave soldering.
- The Pb containing solder is pushed to the top of the PCB during soldering.
- Creating a lower melting point area on topside fillet.
- This then lifts due to difference in solidus temp and volume contraction.

Solder Fillet - PCB “Fillet Lifting”

Occurs when

- **solder tin-rich and contains bismuth**
- **soldering to Sn/Pb coated PCBs and/or component leads/terminations**
- **both of the above together**





Overall view of lifted off region

Other Pb-free wave soldering defects

- Pad lifting
- Inadequate Topside hole filling
- Skips and Bridges
- Microballing

Pb-free wave soldering “Pad Lifting”

- Fillet forms a good joint but the pad is torn away from the PCB
  - real reliability issue
  - greater strength of the Pb-free alloy
  - contraction on cooling not absorbed by creep in alloy
  - do not confuse with fillet lifting
- Increase the area of the pad
  - increases strength of the bond to the PCB

Some general conclusions from Loctite studies

- More stringent requirements for preheating due to more critical thermal dynamics
  - overcome by enhanced preheating, with top and bottom convection heating.
- The oxide layer developing on the top of the SnAgCu alloy is more durable than with SnPb. Deal with this by
  - developing new nozzle structures and improved flow characteristics,
  - more active and sustained flux chemistry
  - phosphorus doping of the solder alloy

More general conclusions from Loctite studies

- Pot and nozzle materials designed for SnPb were found to dissolve into SnAgCu
  - resistant stainless steels were found to be beneficial in these critical areas.
- A steady increase in copper content in the solder bath
  - dealt with by periodically diluting the bath using SnAg as the top-up alloy.
- Drossing rate, lead build up and defect rates, after process optimisation, did not differ from those of earlier SnPb process

More general conclusions from Loctite studies

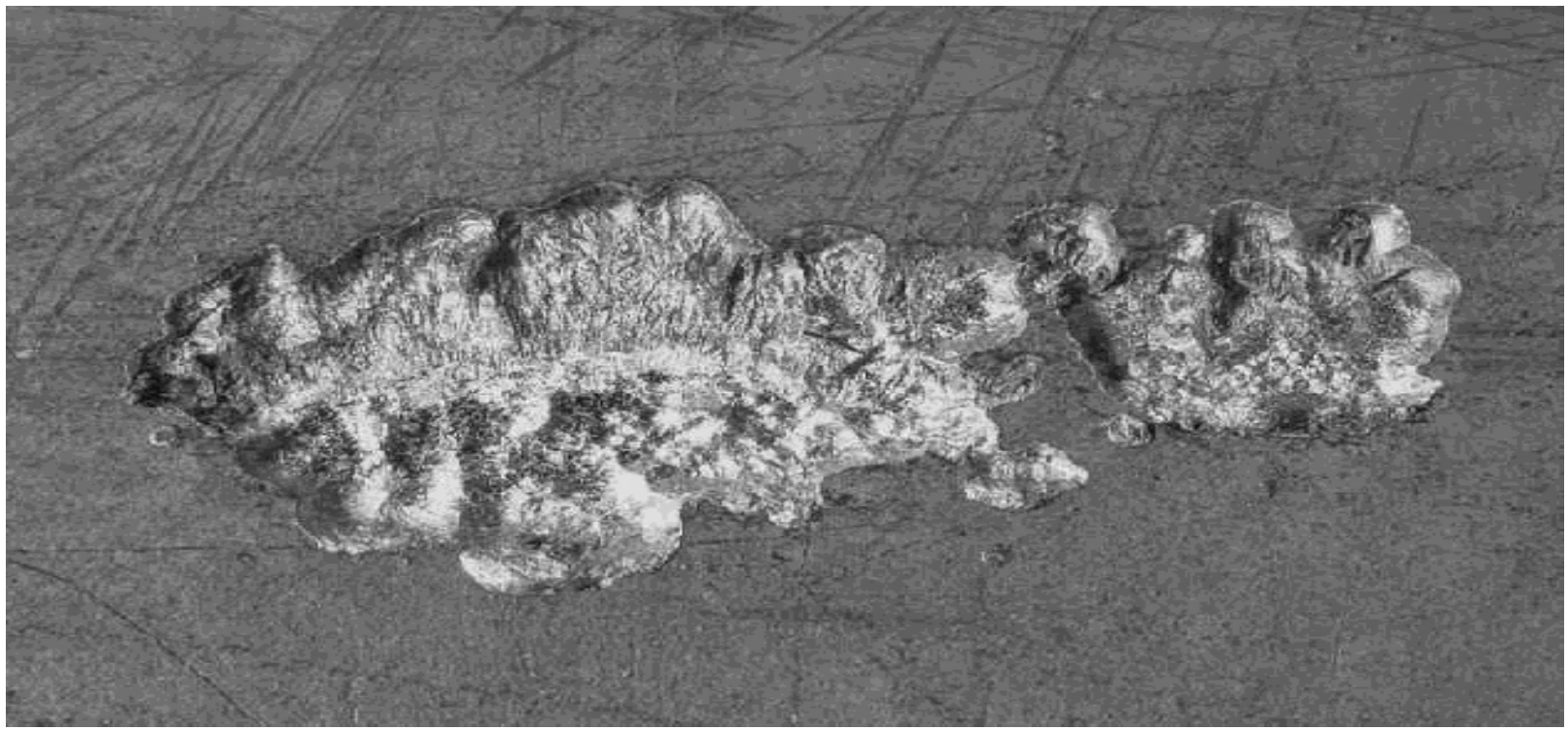
- Avoid alloys with a melting range on through hole boards
  - including melting range created by contaminants
  - not critical for single side boards
- Higher temperatures may require better board support
  - thinner, lower T_g boards show increased warp
- In some ways, implementing a wave soldering process is harder than a reflow process!

Effects of lead free solder on equipment

- The following picture shows an area of 20*9mm on the original wave nozzle front flow guide, where the protective oxide layer on the stainless steel material has broken and wetting has taken place.

The special stainless steel has dissolved to a depth of 0.8mm after only 2 months of use.

Example of lead free solder reacting with stainless steel wave former



Lead free wave soldering

- Tools
  - at present any tools dropped into a lead containing pot float. Making retrieval easy.
  - With lead free most tools will sink. Adding to possible contamination and causing potential damage to machine.

Conclusions

- Most independent industry evaluations agree the best alternative alloy is.
- ***Sn/Ag/Cu***
- Solder looks and feels different.
- Joint inspection criteria will have to be revised for voiding and visual appearance.

VOC Free

VOLATILE ORGANIC COMPOUNDS

- VOC defined as
  - *any carbon containing compound found in the atmosphere excluding CO and CO_2*
- VOCs arise from

transport **refining** **oil & gas production**

chemicals manufacture **agriculture e.t.c.**

- electronics industry not a major contributor

VOCs - Environmental Impact

$$VOC + Sunlight + NO_x = O_3$$

This leads to the formation of photochemical smog at ground level.

Environmental and legislative pressures for reduction in VOC releases from all processes.

VOCs - The Legislation

- United Nations Economic Commission for Europe (UNECE):
  - Protocol to reduce emissions by 30% from a 1988 baseline by 1999.
  - Draft European Directive aims to cut emissions by a further 2/3 by 2007.
  - European Directive on Integrated Pollution Prevention and Control

VOCs - The Legislation

- USA legislation varies from State to State
  - Federal Legislation usually less strict
  - tightest emission levels in California
  - exemption for products <1% VOC content

VOCs - Summary

- VOC emissions lead to production of ground level ozone
- Increasingly subject to legislative control
- Alcohol based fluxes in wave soldering is significant source within electronics industry

VOC Free vs. Standard Fluxes

- Higher activity due to greater acidic dissociation
- Not hazardous for transportation
- Reduced impact on the environment
- Easier disposal
- Non-flammable
- Thinners not required

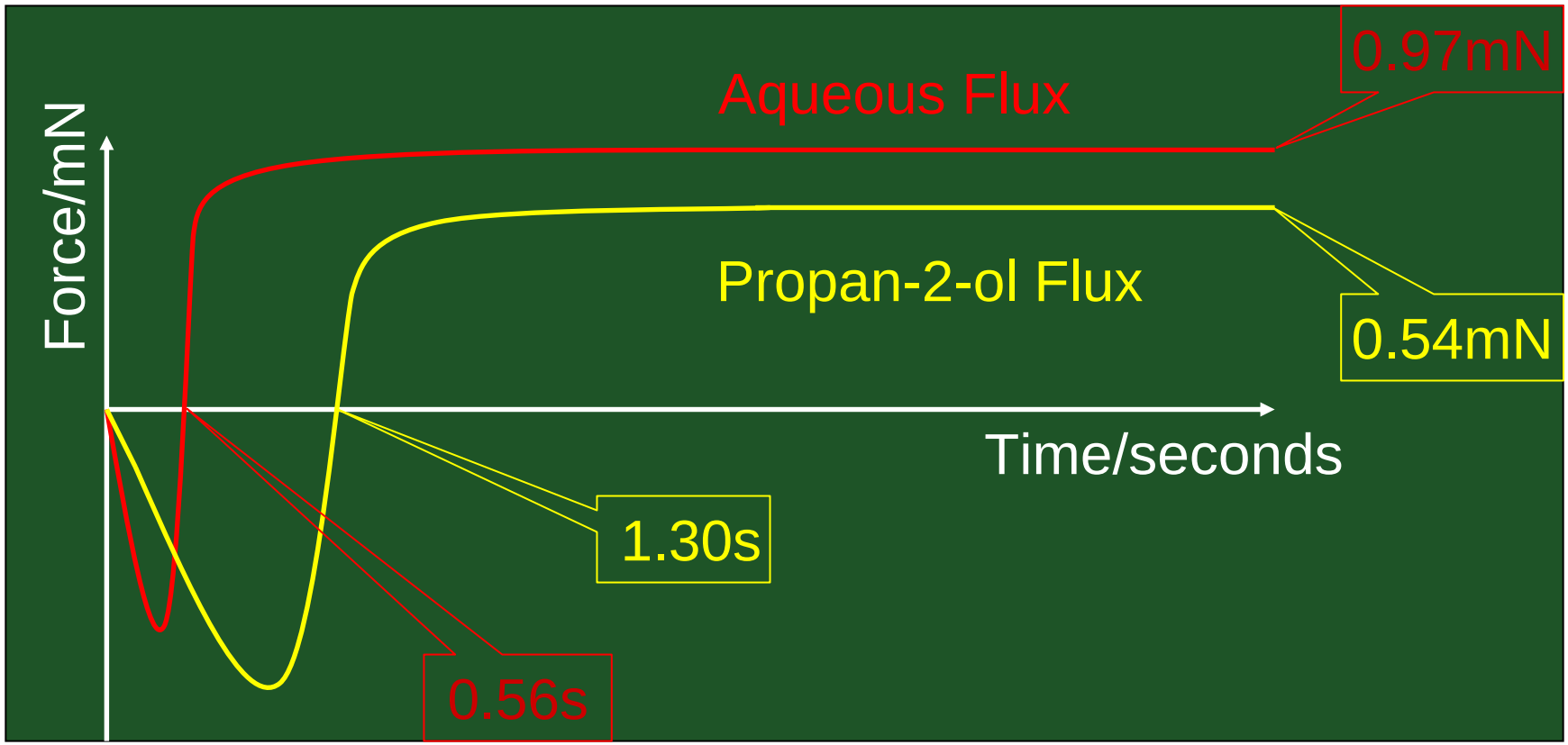
Activation Systems

- Carboxylic acids dissociate:

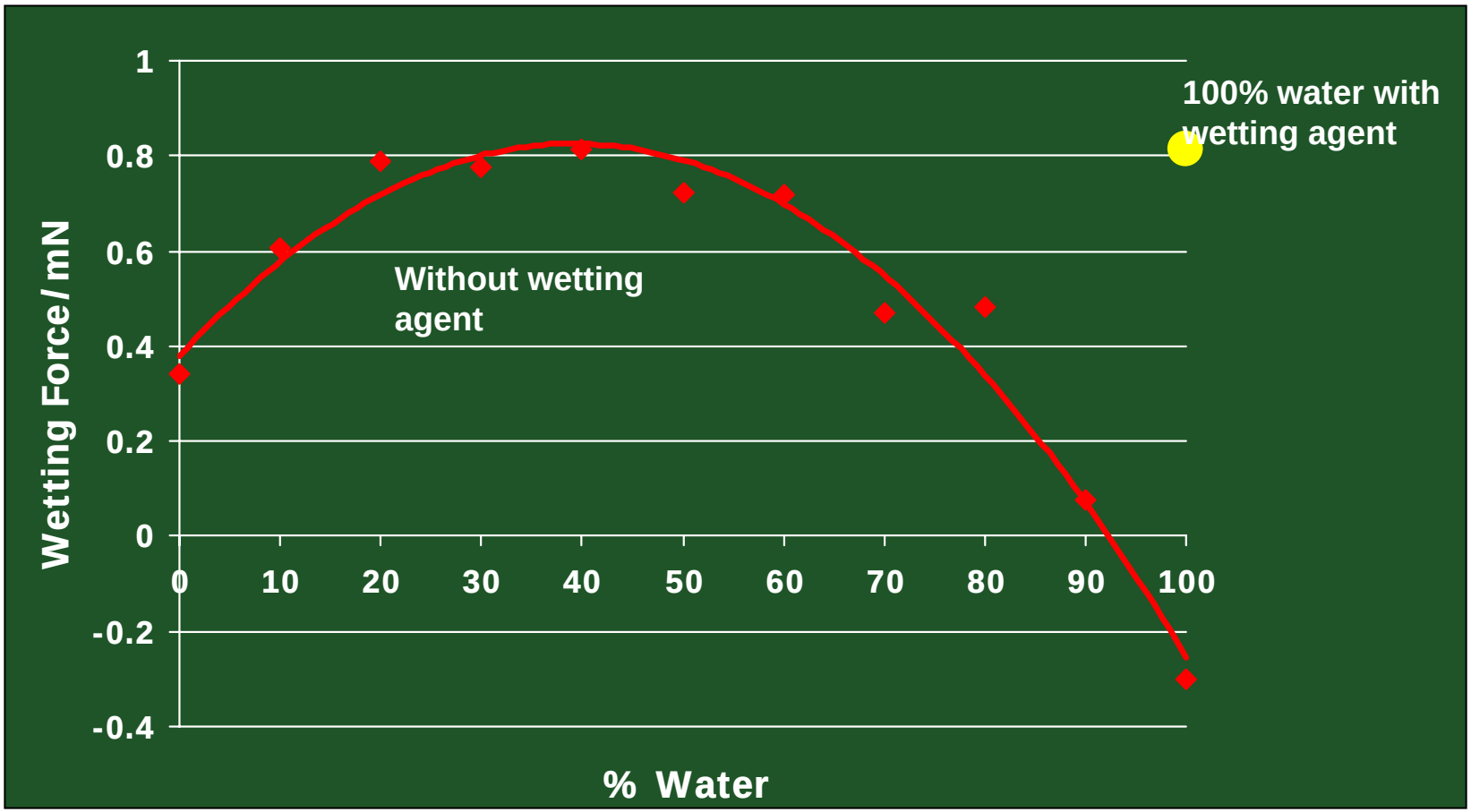
$$RCOOH \rightarrow RCOO^- + H^+$$

- Water is more polar than propan-2-ol and thus favours dissociation
- This enhances fluxing potential

Activation System



Effect of Water on Activity

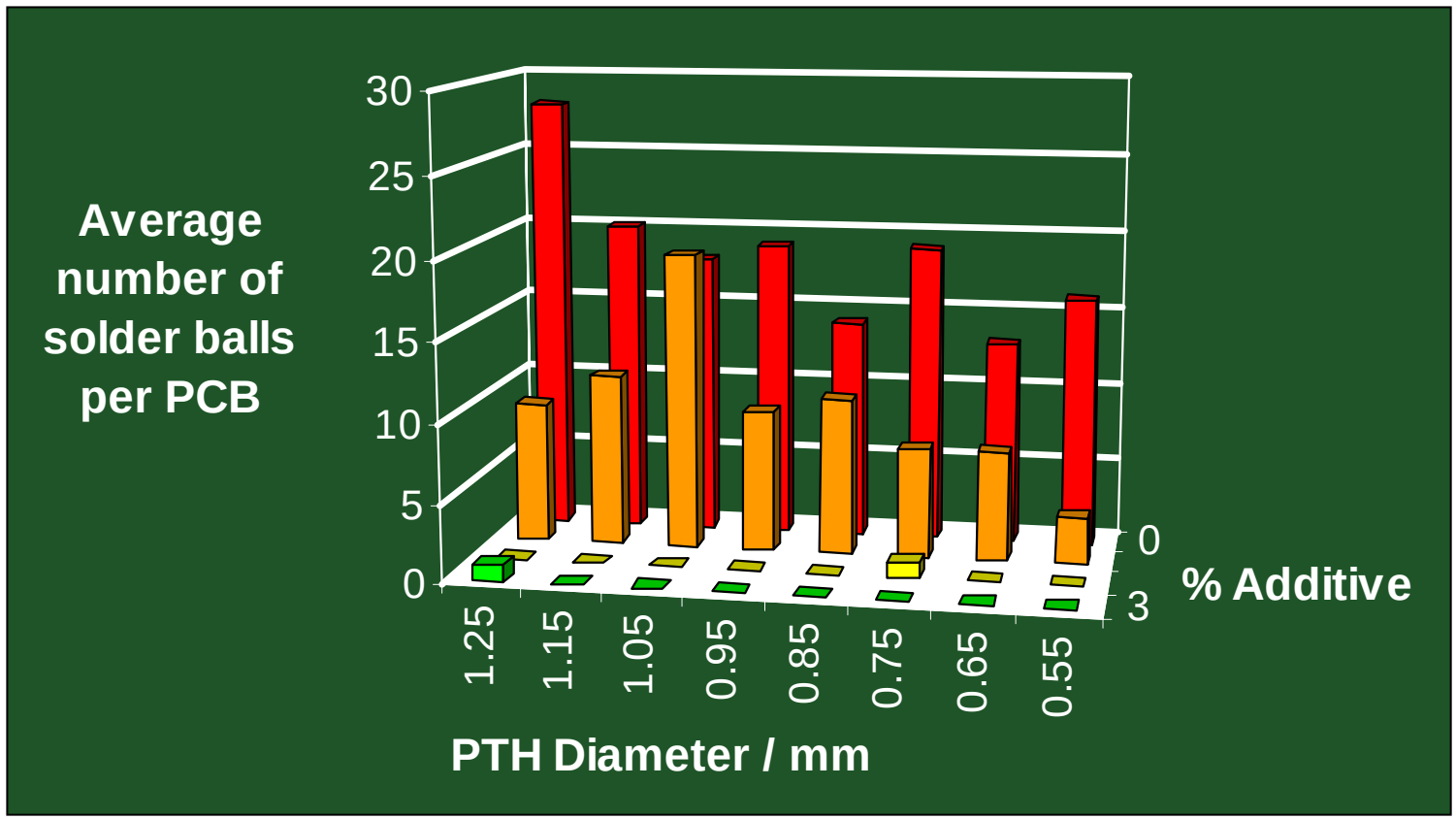


Multicore® MF101
High Activity, No-clean & VOC-free

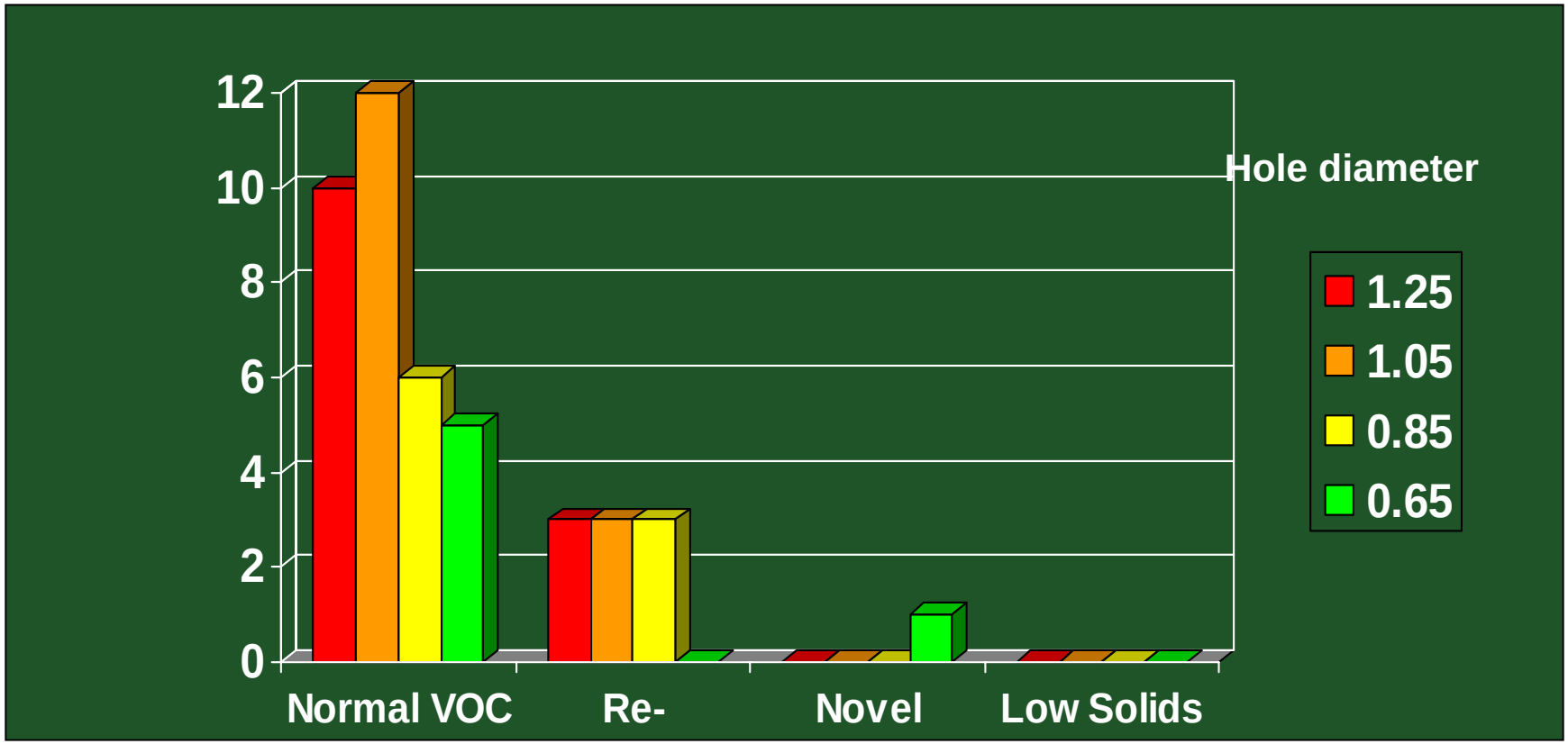
- High activity
  - Wide process window
  - Excellent top-side fillet formation
  - Halide free
  - Passes J-STD and Bellcore SIR
  - Passes Bellcore electromigration

Multicore® MF101

- Sustained activity
  - Specially formulated for low solder balling



Advantages of Novel Formulation



Multicore® MF101

- Validated for lead free processes
  - Thermally stable resin system suited to hotter bath temperatures and varying pre-heat demands

Multicore® MF101

- Higher reliability
  - Natural electrical insulating properties of rosin
  - Bellcore GR-78-CORE SIR results after 5 days (35°C, 85% RH, pattern down)
  - Without rosin - 9.9×10^4 MΩ
  - With rosin - 2.5×10^5 MΩ

Any Questions?

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