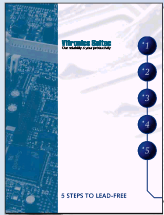
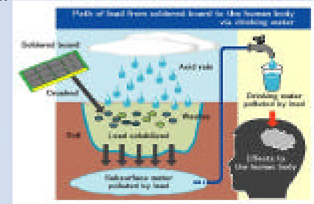
Highlights from the "5 Steps to Successful Lead-Free Soldering"



This methodology is an initiative from the Technology Group of Vitronics Soltec.

Soldering in 2003

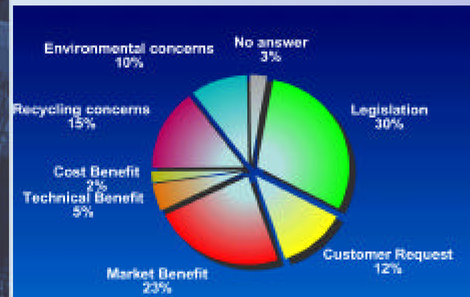
- Leaching of Lead From Used PCB's While in Landfills into Water Supply.
  - Lead Used in Circuit Board Accounts ~ 0.5% - 1% of the Total Amount of Lead Used.



Real Impact of Lead on Humans

- Maximum allowable limit of lead in blood:
  - 10 ug/dl
- Progress made in the last 30 years.
  - 1970's average Pb level = 15 ug/dl
  - 2003 average Pb level = 2 ug/dl
- 80 % of homes built prior to 1978 have lead paint.
  - Danger is when paint chips or in removal which results in Pb dust.
- Affects mental and physical development in kids. Lower IQ and physical stature.

Lead Free Drivers



WEEE and RoHS Directives

- Waste Electrical & Electronics Equipment
- Restriction of Hazardous Substances

- Became law on Feb. 13, 2003
- EU must comply by July 1, 2006

- Notes
  - consumer electronics constitute 40% of lead found in landfills

Contradictions in the Industry

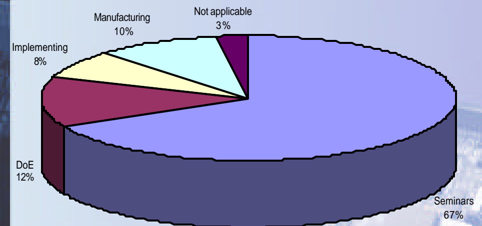
- Philips is formally contesting the WEEE directive on the grounds that it is not environmentally safe.
- Philips is currently manufacturing lead free products.
- Sony Playstation 2 was held up in Dutch customs 11/02 due to elevated levels of Cadmium in the cables.
- Sony reacted by developing an internal group whose only function is to monitor global regulations, develop internal standards, and implement procedures.

JEITA Lead Free Roadmap

Japan Electronics & Information Technology Association

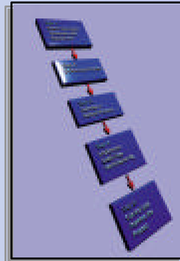
First adoption of lead free solders in mass production	1999
Adoption of Lead Free components	2000
Adoption of Lead Free solders in wave soldering	2000
Expansion of use of Lead Free components	2001
Expansion of use of Lead Free solders in new products	2001
General use of Lead Free solders in new products	2002
Full use of Lead Free solders in all new products	2003
Lead-containing solder used only exceptionally	2005

North American Lead Free Integration



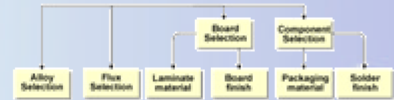
What are the 5 steps?

Step 1: Select the right materials and equipment.
Step 2: Define the Process Parameters.
Step 3: Develop a Robust Process.
Step 4: Implement Lead-Free Manufacturing.
Step 5: Control and Improve the Process.



Introduction 5 Steps

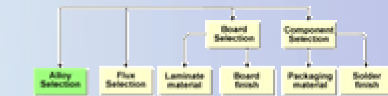
Step 1: Select the right materials and equipment



Critical choices, from alloy and flux selection to necessary equipment capabilities, must be determined first.

1.1 Material selection

1.2 Alloy selection



- Which alloy?
- How to select?

1.2 Alloy selection

Alloy Melting Points

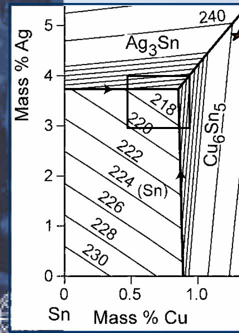
Lead-free alloy selection			
Temperatures		Applications	Concerns
High melting alloys (200-230 °C)			
227	SnCu	Low cost, wave soldering	High temperatures
221	SnAg	Adequate wetting, excellent thermal fatigue properties, reliable joints	Toxicity silver
217	SnAgCu	Wave and reflow, higher tensile strength, recommended by many	Toxicity silver
217	SnAgCuSb	Sb increases reliability for wave soldering	Toxicity silver, antimony, four part alloy
Middle range (180-200 °C)			
200-216	SnAgBi	SMT applications, wave and reflow. Bismuth reduces the melting point	Fillet lifting, Toxicity silver
199	SnZn	Low temperatures	Oxidation of zinc, long-term corrosion of joint, requires special strong fluxes, inclination to dross, poor wetting
Low melting alloys (< 180 °C)			
138	SnBi	Due to low temperature suitable for sensitive components, good fatigue life in SMT, wave soldering	Bismuth is a by-product of lead mining, melting point too low for some applications, fillet lifting

Alloy selection

Tin Silver Copper Alloy

- Choice alloy for NEMI, JEITA, and within EU.
- Composition varies significantly due to:
  - Patented compositions
  - Cost
  - Availability
  - Global Region
- Silver content range: 3.0 - 4.0%
- Copper content range: 0.5 - 0.9%

Alloy Behavior as a Function of Composition



Ag-rich alloys have propensity to form Ag_3Sn.

Cu-rich alloys have propensity to form Cu_6Sn_5.

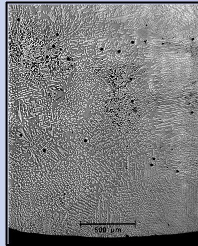
Sn-rich alloys have propensity to nucleate tin dendrites.

Microstructures of Two Different Sn-Ag-Cu Alloys

Sn - 4.7wt%Ag - 1.7wt%Cu

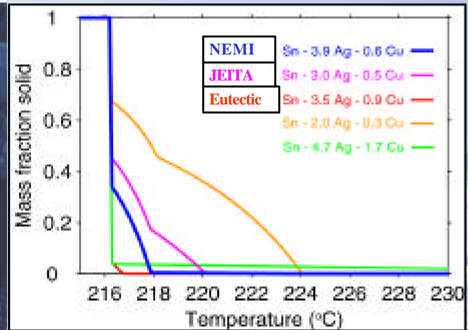
Large Cu_6Sn_5 Present

Sn - 3.2wt%Ag - 0.7 wt%Cu



No Large Cu_6Sn_5 Present

Melting Behavior of Sn-Ag-Cu Solders



Wetting Times lead-free alloys

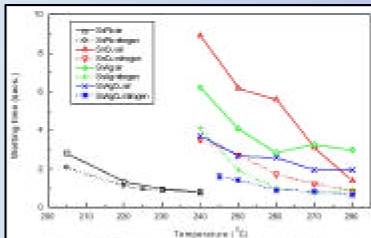
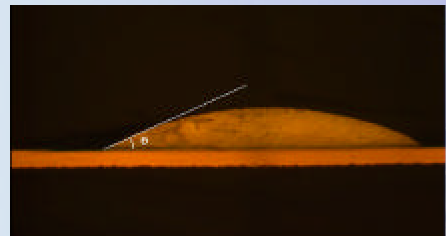


Figure 3 - Wetting Times as a Function of Temperature With a Range Of Alloys With Un-Activated Flux: (a) Air, (b) Nitrogen

Alloy selection

Lead Free Alloy Behavior



Wetting Angle Measurement

Wetting Angle Results

Solder Paste	Reflow Atmosphere	Profile	Average Wetting Angle
Sn/3.8 Ag/0.7 Cu	Nitrogen	Ramp Soak Ramp	27.2
		Direct Ramp	25.7
	Air	Ramp Soak Ramp	27.5
		Direct Ramp	24.4
Sn/3.5 Ag	Nitrogen	Ramp Soak Ramp	22.0
		Direct Ramp	20.5
	Air	Ramp Soak Ramp	27.0
		Direct Ramp	30.0
Eutectic Sn/Pb	Nitrogen	Ramp Soak Ramp	8.9
		Direct Ramp	9.6
	Air	Ramp Soak Ramp	12.5
		Direct Ramp	9.2

Average Wetting Angle Measured by Cross Sectional Analysis

Wetting of lead free is reduced versus tin lead

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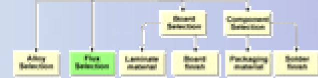
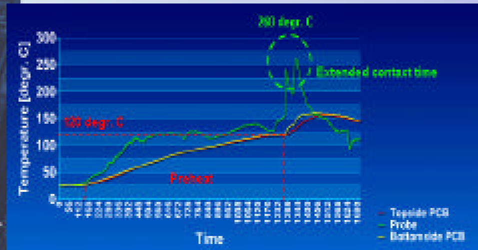
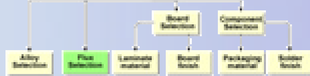
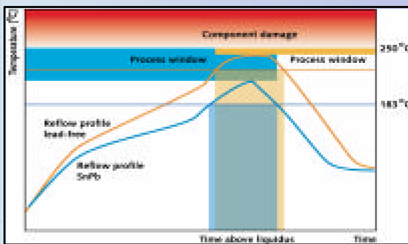
1.3 Flux selection - Wave Soldering





1.3 Flux selection - Paste/Flux





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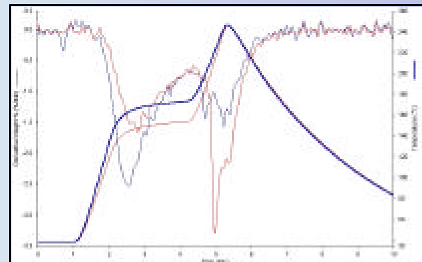
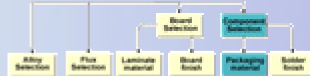
Incompatible Lead Free Flux

- Flux is burned excessively during preheat exposure. Flux becomes "inactive" during reflow portion of the profile.



1.5 Component selection



- Mold compounds and substrates halogen free.
- New plastics need to be designed to meet the higher temperature requirements.
- Lead-free die and passive attachments (NiPd)
- Lead-free solderballs (area array packaging)

1.5a Component selection: packaging material

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Reflow Profile Specifications as Described in J-STD-020B

Reflow Condition	Tin Lead Eutectic Assembly		Lead-Free Assembly	
	Large Body	Small Body	Large Body	Small Body
Average Ramp-Up Rate (T_L to Peak)	3°C/second max.		3°C/second max.	
Preheat - Temperature Min (Tsmin) - Temperature Max (Tsmax) - Time (min to max) (ts)	100°C 150°C 60 – 120 seconds		150°C 200°C 60-180 seconds	
Tsmax to T_L - Ramp-Up Rate	3°C/second max.		3°C/second max.	
Time Maintained Above: - Temperature (T_L) - Time (t_L)	183°C 60-150 seconds		217°C 60-150 seconds	
Peak Temperature (Tp)	225 +0/-5°C	240 +0/-5°C	245 +0/-5 °C	250 +0/-5°C
Time within 5°C of actual Peak Temperature (tp)	10 – 30 seconds	10 – 30 seconds	10 – 30 seconds	20 – 40 seconds
Ramp-Down Rate	6°C/second max		6°C/second max	
Time 25°C To Peak Temperature	6 minutes		8 minutes	

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Component Issues - MSL Rating for IC's - J-STD-020B

- Moisture Sensitivity Level (MSL) rating is has an impact on the entire electronic assembly industry.
- This rating determines humidity exposure limitations prior to using the IC in a reflow soldering process.

LEVEL	FLOOR LIFE		SOAK REQUIREMENTS			
			Standard		Accelerated Equivalent [1]	
	TIME	CONDITIONS	TIME (hours)	CONDITIONS	TIME (hours)	CONDITIONS
1	Unlimited	≤30 °C/85% RH	168 +5/-0	85 °C/85% RH		
2	1 year	≤30 °C/60% RH	168 +5/-0	85 °C/60% RH		
2a	4 weeks	≤30 °C/60% RH	696 [2] +5/-0	30 °C/60% RH	120 +1/-0	60 °C/60% RH
3	168 hours	≤30 °C/60% RH	192 [2] +5/-0	30 °C/60% RH	40 +1/-0	60 °C/60% RH
4	72 hours	≤30 °C/60% RH	96 [2] +2/-0	30 °C/60% RH	20 +0.5/-0	60 °C/60% RH
5	48 hours	≤30 °C/60% RH	72 [2] +2/-0	30 °C/60% RH	15 +0.5/-0	60 °C/60% RH
5a	24 hours	≤30 °C/60% RH	48 [2] +2/-0	30 °C/60% RH	10 +0.5/-0	60 °C/60% RH
6	Time on Label (TOL)	≤30 °C/60% RH	TOL	30 °C/60% RH		

NEMI Lead Free Taskforce - Component Group

- MSL rating increases by 1 level as peak temperature increases by 10°C.
- Floor life of components decrease substantially.
- Involves a transition to increased handling.

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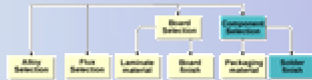
1.5 Component selection



Component finish selection		
Finish	**Application**	**Concerns**
NiPd	SMT components: IC's	Material cost, cracking, solderability
NiPdAu	Alternative for NiPd, slight improved wetting	Material cost
SnBi	SMT components: IC's - Through hole components: IC's, diodes, transistors	Compatibility with tin-lead solder
Sn	Through hole components: CCD	Tin whiskers, relatively high melting point
SnAg (dipping)	SMT components: diodes - Through hole components: IC's, transistors and diodes	Plating feasibility not established/proven
SnCu	Through hole components: diodes	Tin whiskers, light percentage copper, control established

1.5b Component selection: Solder finish

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Post Reflow Visual Inspection 2512 Resistor

Shiny | *Grainy* | *Shiny - Less Wetting*

SnPb paste/ SnPb 2512 resistor

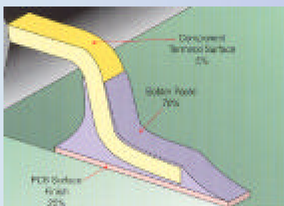
SnAgCu paste / SnPb 2512 resistor

SnAgCu paste/ Pure tin 2512 resistor

Lead-free SnAgCu soldered lead-free resistor component has less wetting than tin-lead soldered component

What is Lead Free?

- NEMI recommends total lead amount = 0.2%
- JEITA limits lead content to 0.1%
- WEEE directive limits lead content to 0.1%



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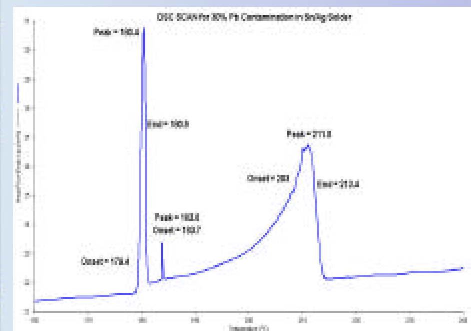
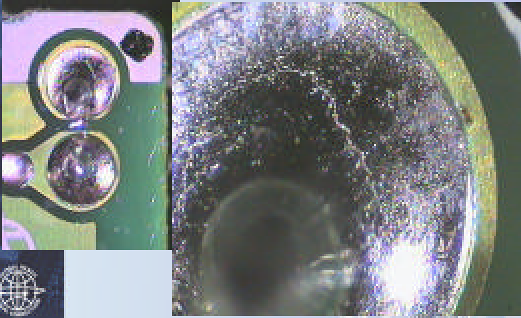
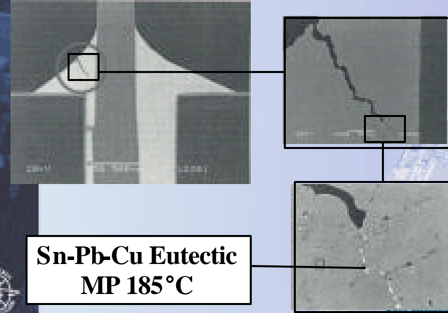
Sn/Ag with 30% Pb



Impact of Pb Contamination > 0.5%



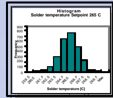
Impact of Pb Contamination > 0.5%

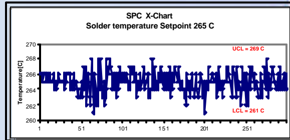


Sn-Pb-Cu Eutectic
MP 185°C

3.5 Collect data

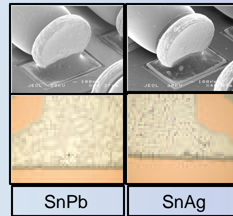
Use SPC to monitor variations and trends.
• Contact times, solderpot and preheat temperatures.
• Time above liquidus, peak temperatures, cooling rates.





3.5 Collect data

3.6 Evaluate yields and reliability



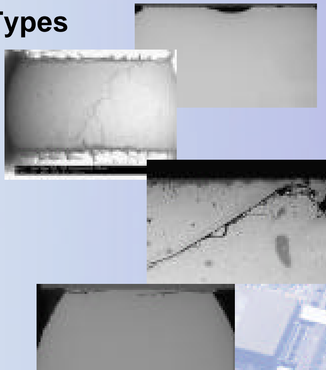
SnPb SnAg

Compare the results of the lead-free process with the standards of the SnPb process.

3.6 Evaluate yields and reliability

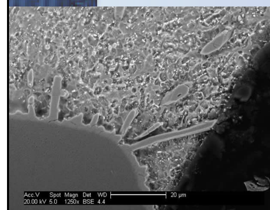
Failure Types

- Dewetting
- Cracking
- Intermetallic

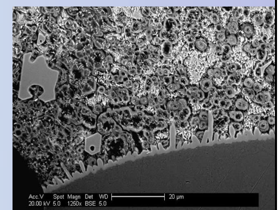


Intermetallic Growth during Aging

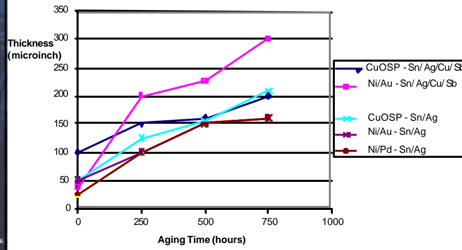
500 hrs @ 125°C



time 0



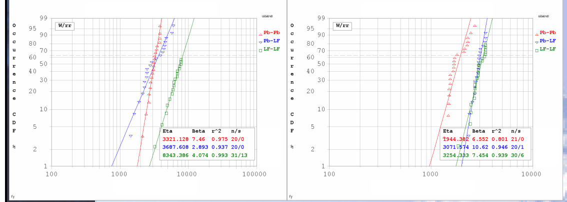
Impact of Aging on Intermetallic Growth



169CSP Weibull Analyses

0 to100°C cycling

-40 to +125°C cycling



	Pb-Pb	Pb-LF	LF-LF
η (N63)	3321	3688	8343
β	7.5	2.9	4.1

	Pb-Pb	Pb-LF	LF-LF
η (N63)	1944	3071	3254
β	6.6	10.6	7.5

Lead Free Alloys Today

Variability of microstructure is not yet safely accounted for. Increasingly critical for smaller joints.

- Variation with reflow profile (t, T, ΔT/Δt, conc.), pad metallurgy combinations, aging.
- Impact of electromigration.
- Significant effects of very small process variations.
- ‘Mixed’ assemblies/ Pb contamination.

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