

## Lead-free Soldering – A Challenge For Base Materials

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On February 13<sup>th</sup>, 2003, the European Parliament and the European Commission announced and published the so-called RoHS directive, dealing with the "Restriction of the use of certain Hazardous Substances" in electrical and electronic equipment.

This directive was converted in national laws and from July 1st, 2006 on so-called hazardous substances like mercury, cadmium, lead, chromium VI will be dramatically reduced in industrial products in order to support the waste treatment regulations as well as recycling processes of components.

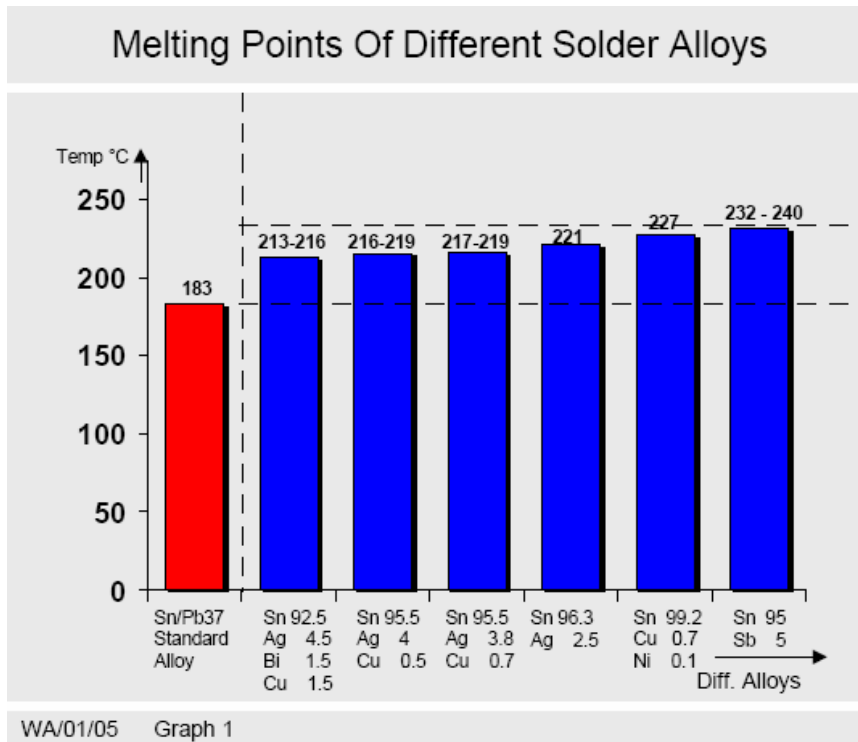
Our industry is also heavily affected due to restriction resp. ban of lead in electronic systems. There are also exceptions defined such as electronic systems being used in medical equipment, control and supervision systems as well as networking infrastructure equipment.

Since more than one year the industry is following this direction consequently and will be prepared along the value chain.

Leading OEMs and CEMs, also outside Europe, have officially announced to have lead-free soldering implemented earlier than the requested time line. Japanese companies like MATSUSHITA, HITACHI, SONY, PANASONIC are actively working on the lead substitution in their products, European OEMs like SIEMENS, ERICSSON, NOKIA, BOSCH or American OEMs are on the same track.

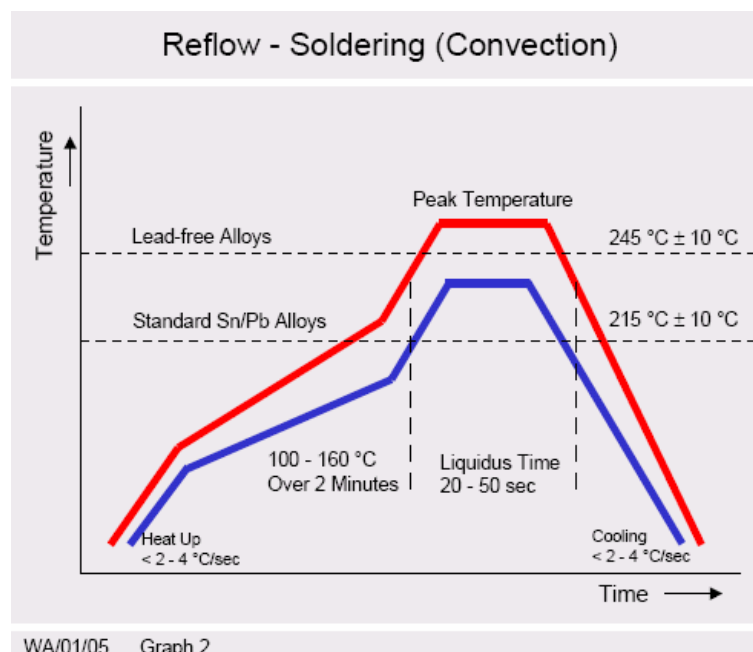
Different lead-free solder alloys have been evaluated for lead-free soldering of pcbs. Picture 1 shows a comparison of the different alloys regarding their melting points.

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Since the actual solder temperature is 20 – 30 °C higher than the melting point of the alloy, the peak temperature at soldering will increase from ~ 215 ± 10 °C to 245 ± 10 °C maximum for appr. 20 seconds (reflow convection oven).

A typical temperature-time profile for a reflow process is shown in graph 2.



What does it mean for the base material of a pcb, if the peak temperature increases from 220 °C up to 250/260 °C?

What are problems that can occur and how to avoid them?

The thermal behaviour of a base material is mainly determined by:

- ™ the resin type
- ™ the crosslinking agent
- ™ the degree of crosslinking
- ™ the decomposition temperature of the resin system
- ™ adhesion of resin to carrier material (glass cloth)
- ™ additives f. e. fillers

Today, mostly used resin types are di-, tetra- or multifunctional epoxy resins with a Tg ranging from 135 up to 180 °C. Curing agents used for epoxy resins are dicyandiamide or novolacs (phenolic cured).

The degree of crosslinking is defined by the temperature and corresponding time the laminate sees during the press process. The adhesion of the resin to the glass fabric is defined by the finish type on the glass fiber. Finally, the thermal behaviour of base materials in thermal cycling tests can be improved by adding appropriate fillers to the resin system.

Predominantly, the Tg value was the only criteria for thermal performance of a resin system. This has been proven to be inadequate, since the Tg is only one out of other characteristics which all together give the full picture of thermal reliability needed f. e. at lead-free soldering. In other words: The Tg tells you really little serious about the thermal reliability of the polymer. More important characteristics to describe the thermal behaviour are the T-260 resp. T-288 tests, thermal decomposition temperature Td and the thermal degradation at

elevated iso thermal temperatures of the resin matrix in a defined time window (for example 1 hour at 220 °C, 240 °C, ...).

Those characteristics are the T-260 resp. T-288 values and the decomposition temperature of the resin system. Graph 3 shows the relationship between the Tg, the time to delamination measured at two different temperatures and the decomposition temperature of a selection of substrates.

## Thermal characteristics on different basematerial

Base Material	Curing System	Tg	T-260 °C Minutes	T-288 °C Minutes	T <sub>D</sub> °C
FR4 Epoxy High Tg	Dicyandiamide	175 °C	8	0	300
FR4 Epoxy Mid range Tg	Dicyandiamide	150 °C	10	0	305
FR4 Standard Tg	Dicyandiamide	135 °C	15	0	315
FR4 Epoxy High Tg	Phenolic Family	175 °C	>60	40.0	360
FR4 Epoxy Mid range Tg	Phenolic Family	150 °C	>60	9.1	340
FR4 Standard Tg	Phenolic Family	135 °C	>60	12.8	357

WA/01/05 Graph 3

The table shows clearly for this group of substrates that it is the combination of the resin system and the curing agent that determines the thermal reliability and not the Tg.

During the production and at final inspection several thermal tests are performed with the base material acc. to IPC-specifications and others, such as:

- ™ Glass transition point (Tg 1 and Tg 2)
- ™ Thermo mechanical analysis (time to delamination @ 260 °C and/or at 288 °C)
- ™ Solder float and solder dip test @ 260 °C or even @ 288 °C
- ™ Coefficient of thermal expansion (CTE <sub>z</sub>).

The criteria are degree of curing ( $T_g$  resp.  $T_g$ ) and delamination/separation in the base material.

Since most of the a. m functional testings are performed and passed at temperatures and conditions @ 260 °C and higher from a laminate point of view, the lead-free soldering is not being considered as a problem.

Can this situation change on MLB-level?

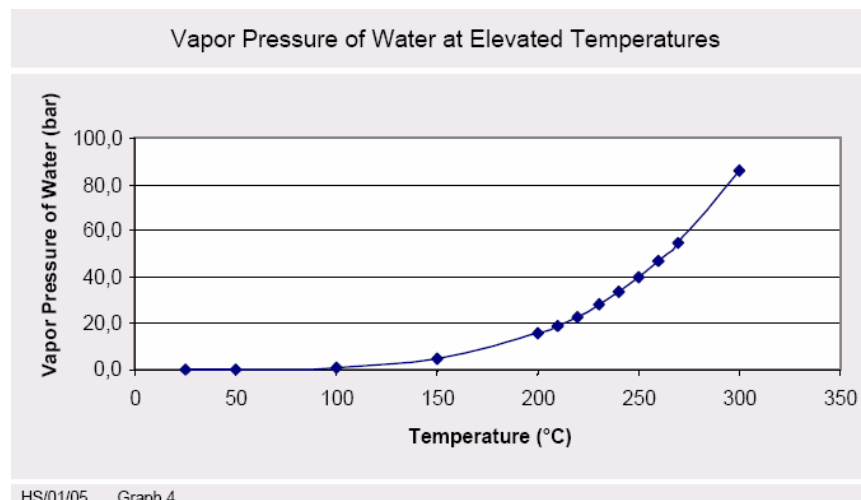
Yes, it can.

Investigations have shown that f. e. the time to delamination at 260 °C ( $T_{260}$  –test in TMA) on laminate level can last from 10 up to more than 60 minutes, whereas on MLB-level the time can be significantly lower for the same resin matrix.

Manufacturing processes that are needed for MLB production can influence the thermal behaviour during lead-free soldering (f. e. black/brown oxide or alternatives, pressing at relamination, drilling parameters, hole cleaning, moisture pick-up etc).

Furthermore, the design of the pcb also has a great influence on the thermal resistance during lead-free soldering.

Remaining moisture or chemicals in the MLB can also generate problems/delaminations due to increased vapor pressure at elevated temperatures.



The graph shows clearly that the vapor pressure is more than 2 x higher by increasing the solder temperature from 220 °C to 265 °C. An appropriate drying process prior to lead-free soldering is therefore strongly recommended.

Remark: Resin systems with an appropriate filler can increase the thermal resistance due to reduced humidity pick-up and a lower z-axis expansion to protect the material against thermal-mechanical stress.

In order to evaluate the lead-free solder behaviour not only on laminate, but also on MLB level, Isola together with leading pcb manufacturers in Europe performed a matrix on different base materials with different designs.

The lead-free solder process was performed at SEHO, Kreuzwertheim, Germany.

The following base materials have been evaluated:

Lead-free solder matrix		
<b>Unfilled Systems</b>		
STD Tg Epoxy	Tg 135	DE 104
Hi Tg Epoxy	Tg 170/180	DE 117 IS 410
<b>Filled Systems</b>		
Mid Tg Epoxy	Tg 150	IS 400
Hi Tg Epoxy	Tg 175	IS 420
<b>Halogenfree</b>		
Mid Tg System	Tg 155	DE 156

WA/01/05 Graph 5

The boards have been soldered without devices. The lead-free solder process included the following process steps:

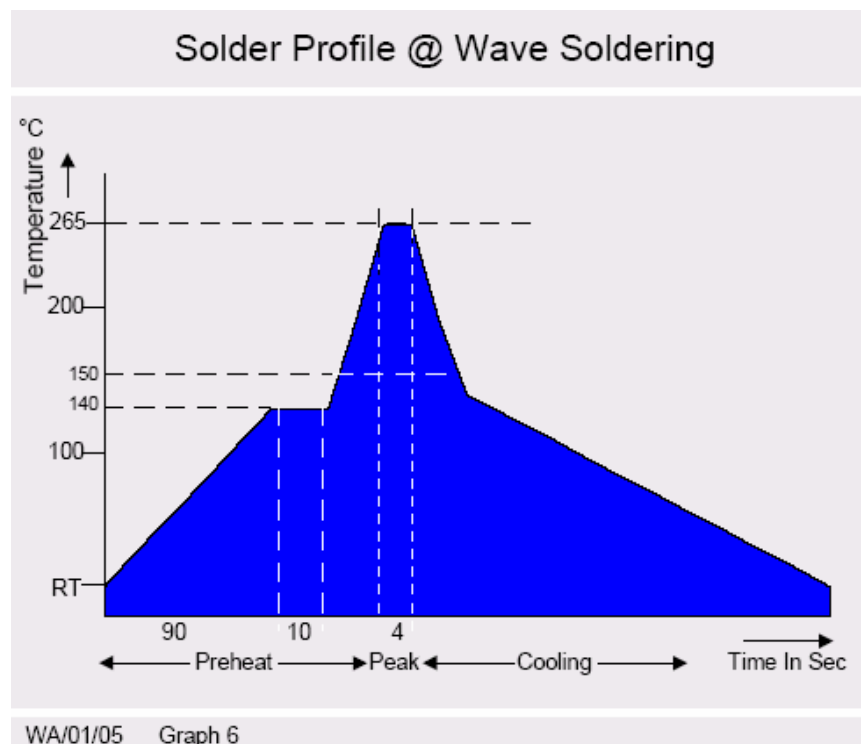
- 2 x wave soldering
- 2 x – 4 x reflow.

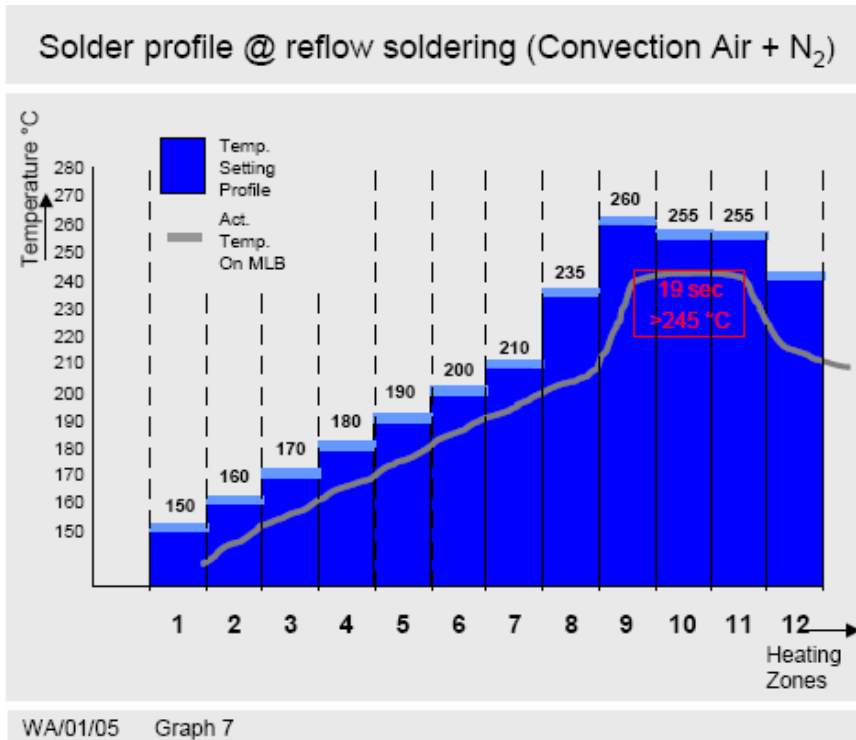
The solder alloy being used at wave soldering contained

- 99.2 % Sn
- 0.1 % Ni
- 0.7 % Cu

The melting point of this alloy is 227 °C, whereas the solder temperature was @ 265 °C with a contact time of 3 – 4 sec. The MLB was preheated prior to soldering up to 130– 140 °C.

The solder profiles of the wave solder process and the reflow process are shown in graph (6) and graph (7).





After several reflow processes the MLB's have been sectioned and inspected. The results will be introduced and discussed in detail during the lecture.

## Lead Free Soldering Results With Different Base Materials

- Different MLB's have been processed after drying (2 hrs @ 130 °C resp. 150 °C, pending on Tg)

2 x wave soldering  
and in addition  
several times through  
reflow process

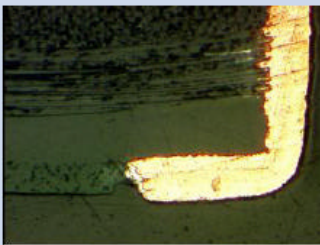
- The MLBs have been cross-sectioned and pending on their thermal characteristics, we have received the following results:

WA/01/05 Graph 8

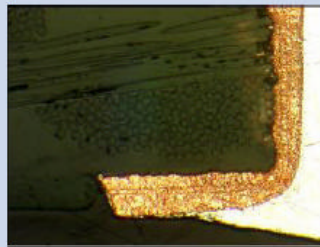
## Lead Free Soldering Results With Different Base Materials

STD. FR-4, Tg 135 °C

2 x Wave Soldering



2 x Wave Soldering And  
2 x Reflow Process

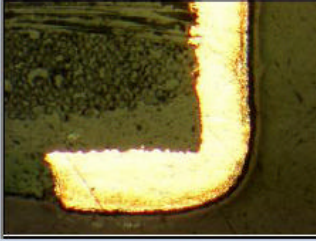


WA/01/05 Graph 9

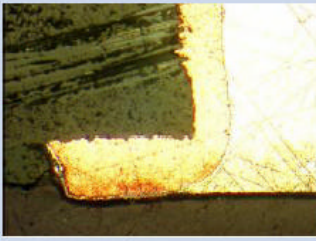
**Lead Free Soldering Results With Different Base Materials**

High Tg Epoxy, Tg 175 °C, Filled System

2 x Wave Soldering








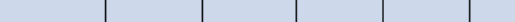
2 x Wave Soldering And  
5 x Reflow Process



WA/01/05 Graph 10

**OVERVIEW**

**Lead Free Soldering Results With Different Base Materials**

Curing Agent	Product Type	2 x Wave Soldering	Reflow Process				
			1 x	2 x	3 x	4 x	5 x
Dicy Brominated	STD FR-4						
	High Tg Epoxy						
Novolac Brominated	High Tg Epoxy						
	Mid Tg Epoxy (Filled)						
	High Tg Epoxy (Filled)						
Dicy Halogen Free	Mid Tg						

WA/01/05 Graph 11

## S U M M A R Y

- The thermal behaviour of a base material is not defined by one characteristic, e. g. the Tg, but by
  - Resin type
  - Crosslinking agent
  - Degree of crosslinking
  - Decomp. temp. of resin system
  - Adhesion of resin to carrier material
  - Additives/fillers
- Lead free soldering increases the thermal stress on PCB level
- Base materials with improved thermal stability are proven, commercially available and in use
- Pending on the requirements, different resin systems should be applied

WA/01/05 Graph 12

## S U M M A R Y Cont'd

- PCB manufacturing processes influence solder results
- Design of PCB/MLB may not be underestimated

WA/01/05 Graph 13

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THANK YOU FOR YOUR ATTENTION

QUESTIONS?

## Biographies



**Wolfgang Alberth** is Director OEM Marketing Europe for Isola. He joined Isola in 1996 and held several Management positions in both, manufacturing and product development. Previously he was working 14 years for IBM in Germany as Process Engineer for pcb production and later being involved in Management of pcb process and product developments for standard and advanced technologies. Wolfgang holds a B. Sc. Degree in metallurgy from University of Applied Science in Aalen, Germany.



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