Lead Free Soldering Technology

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Requirements of Lead-Free Technology

SEHO GmbH

rahn-tec

Multicore

STANNOL

Experts and Information
Task Force
„Lead-Free Soldering“

AIR LIQUIDE

Problems:

- Fault rates
- Reliability
- Process parameters
- Compatibility of machines
- PCB materials and components

How does lead-free soldering effect the soldering process?

probably the new solders will be based on a higher content of tin

⇩

higher melting point

⇩

higher process temperatures

⇩

increased risk of oxidization

Alternative Solders:

– Sn99,3–Cu0,7	MP: 227 °C
– Sn95,8-Ag3,5-Cu0,7	MP: 216 °C
– Sn96,5-Ag3,5	MP: 221 °C
– Sn91,7-Ag3,5-Bi4,8	T_S: 205 °C
	T_L: 210 °C

Substitution of lead
Metal prices (Condition: May 2000)

Production of solder in FRG (1996/97): 1.100 ... 1.600 t/Month

Lead: 1.0/kg **Tin: 13.4/kg**

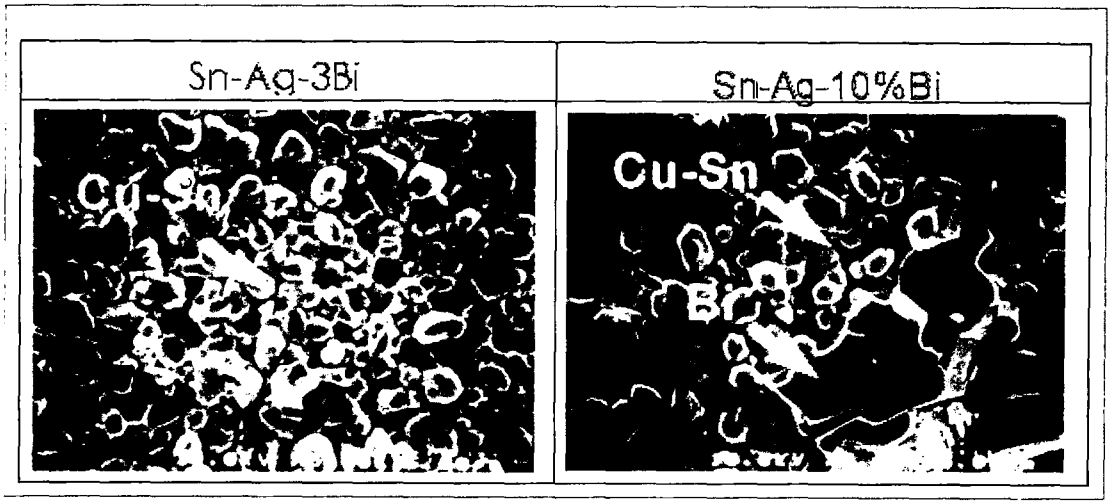
Copper (Cu):	4.5	/kg
Bismut (Bi):	22	/kg (12/09/99)
Cadmium (Cd):	9	/kg (1998)
Zink (Zn):	2.8	/kg
Aluminum (Al):	3.6	/kg
Nickel (Ni):	26	/kg
Silver (Ag):	420	/kg
Indium (In):	590	/kg (03/20/00)
Antimon (Sp):	5,5	/kg (04/03/00)
Gold (Au):	21450	/kg

Lead-Free Technology

Alloy: Sn95.5 Ag3.8 Cu0.7		Alloy: Sn96 Ag4		Alloy: Sn99 Cu1	
Price: 1 /kg		Price: 1.02 /kg		Price: 0.49 /kg	
Tin:	95,39 %	Tin:	96,23 %	Tin:	99,22 %
Lead:	0,03 %	Lead:	0,04 %	Lead:	0,04 %
Copper:	0,6000 %	Copper:	0,0029 %	Copper:	0,7500 %
Silver:	3,9100 %	Silver:	3,7000 %	Silver:	<0,0005 %
Iron:	0,0193 %	Iron:	0,0035 %	Iron:	0,0036%
Antimon:	0,0112 %	Antimon:	0,0105 %	Antimon:	0,0073 %
Arsen:	0,0020 %	Arsen:	0,0021 %	Arsen:	0,0015 %
Bismuth:	0,0018 %	Bismuth:	0,0019 %	Bismuth:	0,0019 %
Cadmium:	<0,0001 %	Cadmium:	<0,0001 %	Cadmium:	0,0001 %
Zinc:	0,0012 %	Zinc:	<0,0005 %	Zinc:	<0,0005 %
Aluminium:	<0,0005 %	Aluminum:	<0,0005 %	Aluminum:	<0,0005 %
Nickel:	0,0013 %	Nickel:	0,0012 %	Nickel:	0,0013 %
Gold:	0,0004 %	Gold:	0,0003 %	Gold:	0,0003 %
Indium:	0,0029 %	Indium:	0,0034 %	Indium:	0,0034 %
Phosphorus:	0,0130 %	Phosphorus:	0,0115 %	Phosphorus:	0,0118 %

Lead-Free Technology

Bismuth in Tin-Silver



Baggio NW 00

At 5 % Bi already, bismuth refines from the SnAgBi matrix. This separation of bismuth weakens the solder joint.

Pb-Impurity with Bi-Solders

When the Pb-level reaches 0.5 %, the tension stress of a through-hole solder joint only will be 60 % compared to a solder joint without Pb.

Baggio NW 00

Significance of Lead in the Electronics Industry

USA: Surface Mount Council; White Paper: „An Assessment of the Use of Lead in Electronic Assembly", SMC-WP-002, August 1992:

⇨ **approx. 0.6 % of the total Pb consumption in electronic solders**

Japan: IPC-Review, August 1998, P. 4 a. 6: „Japan Enviromental Movement Showing its Metal"; Japan Electronic Industry Promotion Assn. (JEIPA):

⇨ **approx. 3 % (≅ 9.000 t) of the yearly consumption of Pb in electronics**

Germany: Production rates published by the government (1997): approx. 20,000 t/month lead; solders: approx. 1,300 t/month with an average Pb part of approx. 50 %

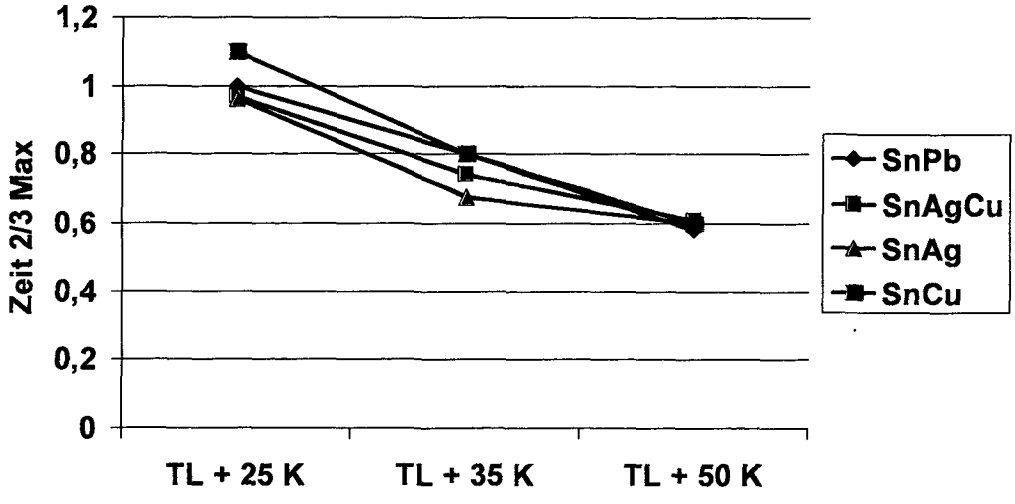
⇨ **approx. 3 % of the Pb production in solders**

Quelle: Siemens

Common Characteristics:

- higher melting point compared to Sn63Pb37
  - ➢ higher using temperature
  - ➢ wave: 295, 285, 290 resp. 280 °C (?)
  - ➢ reflow: 265, 255, 260 and 250 °C (?)
- higher content of tin
  - ➢ increased diffusion

Wettability



IDEALS Projekt

Lead-Free Technology

IPC Roadmap for Lead-Free Electronic Assemblies

Alloys Used by Area of Industry Served:

INDUSTRY SERVED	COMPANY	ALLOYS USED
Automotive	Panasonic	SnAgCu
	Visteon (Ford)	96.5Sn3.5AG 96.5Sn3.0Ag0.5Ni 96.5Sn2.5Ag1.0Ni 96.5Sn2.5Ag0.5Ni0.5Cu 96.0Sn2.0Ag1.0Ni1.0Cu 95.0Sn3.0Ag1.0Ni1.0Cu 94.0Sn2.0Ag2.0Ni2.0Cu
Telecommunications	Nortel	Sn3.8Ag0.7Cu Sn0.7Cu
	Toshiba	SnAgCu
	Nokia	SnAgCu
	Panasonic	SnAgCu
Industrial	No Resourcees Available	
Business/Retail	No Resources Available	

INDUSTRY SERVED	COMPANY	ALLOYS USED
Consumer	Hitachi	SnBiAg
	Panasonic	SnAgBiX SnCu SnZn SnBi
	Toshiba	SnZn
	Sony	Sn2.0Ag4.0Bi0.5Cu0.1Ge
	NEC	SnZn
Instrumentation	No Resources Available	
Military/Aerospace	Panasonic (FA Controller?)	SnAgBiCu SnAgBi

Lead-Free Technology

IPC Roadmap for Lead-Free Electronic Assemblies

Alloys Researched by Organization:

Organization	Alloys
NEMI	Sn0.7Cu Sn3.5Ag SnAgCu
NCMS	Sn3.5Ag Sn58Bi Sn3.0Ag2.0Bi CASTIN Sn3.4Ag4.8Bi Sn2.0In2.8Ag (Indalloy) Sn3.5Ag0.5Cu1.0Zn
PCIF / ITRI	SnAgCu

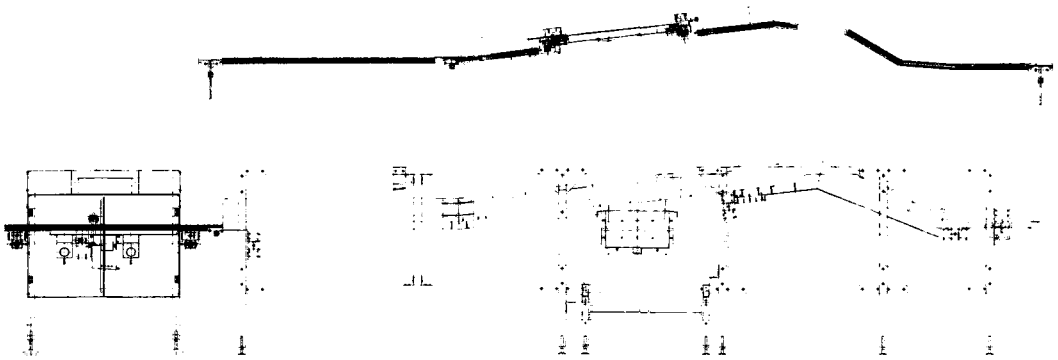
IPC Roadmap for Lead-Free Electronic Assemblies

Molded Components:

Finish	Manufacturing Experience	Concerns
NiPd	YES	Material cost (Process is cheaper, must switch 100%)
NiPdAu	YES	Materiual cost
SnBi	NO	The assembly must be totally Pb free
Sn	YES	Tin Whiskers

Values for Wave Soldering

- time above liquidus (T_L)
  - diffusion area < 2 µm
  - 17 - 20 seconds
- glassy point T_g
  - FR-4 ~ 145 °C
- temperature rise preheating / wave
  - < 100 K



General:

- changes in machine technology depend on the solders and pastes that will be used in the future
- SEHO already has made tests with all those lead-free products that are expected to gain market shares
- should there be new fluxes and/or other alloys that gain favor, SEHO will test those thoroughly in a number of systems too

Wave Soldering Systems

- Solder pot
  - material
  - solder impurity
  - catalytic effect
- Pumps
  - abrasion
- Pre-heating
  - temperature rise preheating / wave

SEHO Wave Soldering Systems
Test Results

	tin-silver-copper Sn95Ag4Cu mp: 217°C	tin-silver Sn96Ag4 mp: 221°C	bismuth-tin Bi57Sn43 mp: 138°C
fluxing area	standard	standard	standard
pre-heating zone	- higher preheating temp. necessary - powerful preheating necessary - the preheating may be upgraded by SEHO if necessary	- higher preheating temp. necessary - powerful preheating necessary - the preheating may be upgraded by SEHO if necessary	standard

SEHO Wave Soldering Systems

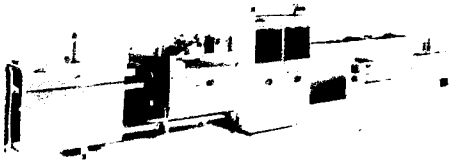
Test Results

	tin-silver-copper Sn95Ag4Cu mp: 217°C	tin-silver Sn96Ag4 mp: 221°C	bismuth-tin Bi57Sn43 mp: 138°C
soldering zone	- peel-off angle must be calibrated to suit. SEHO's standard covers soldering calibration - SEHO's standard solderpots meet required temperatures	- peel-off angle must be calibrated to suit. SEHO's standard covers soldering calibration - SEHO's standard solderpots meet required temperatures	- peel-off angle must be calibrated to suit. Standard soldering angles (max. 8°) are usually insufficient. Good results may be obtained with 10 – 13°. Special upgrading necessary. - ATTENTION: Bismuth expands during solidification. Solderpots must be adapted accordingly

SEHO Wave Soldering Systems

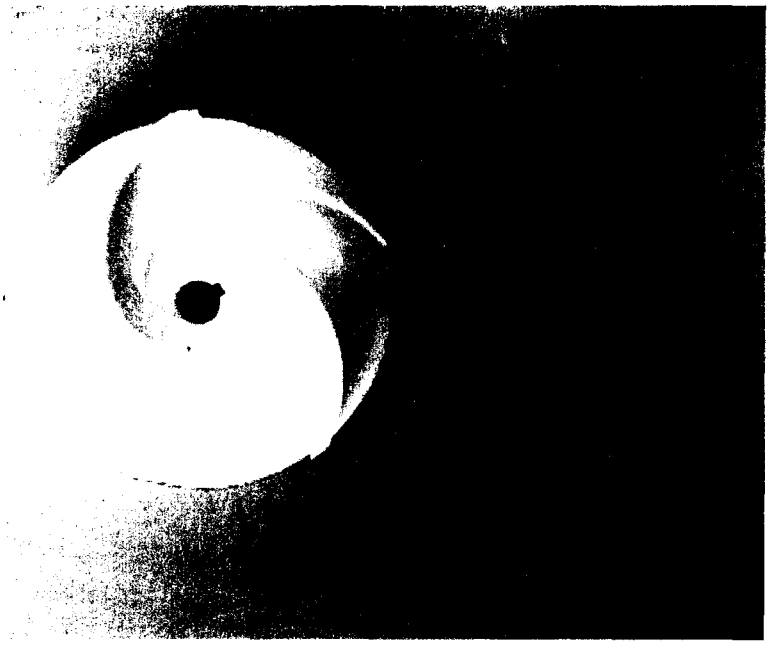
Test Results

	tin-silver-copper Sn95Ag4Cu mp: 217°C	tin-silver Sn96Ag4 mp: 221°C	bismuth-tin Bi57Sn43 mp: 138°C
process chamber	- increased oxidation, consequently nitrogen atmosphere recommendable (full tunnel unit)	- increased oxidation, consequently nitrogen atmosphere recommendable (full tunnel unit)	- increased oxidation, consequently nitrogen atmosphere recommendable (inertization in wave zone sufficient)



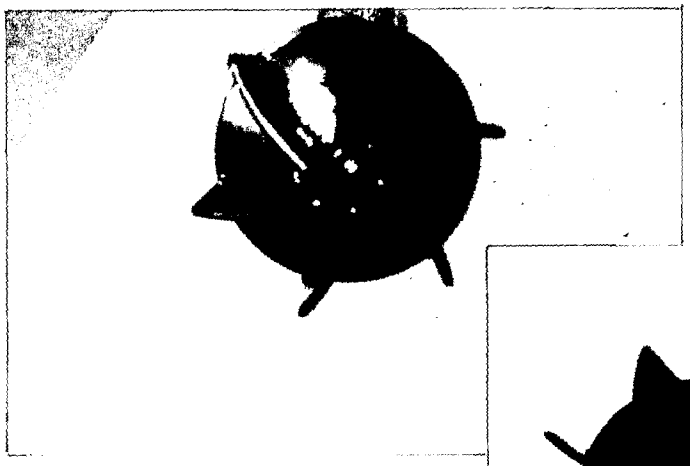
SEHO Selective Soldering Systems
Test Results

tin-silver-copper Sn95Ag4Cu mp: 217°C	tin-silver Sn96Ag4 mp: 221°C	bismuth-tin Bi57Sn43 mp: 138°C
- similar requirements as for wave soldering machines - SEHO's MWM 3250 is designed for lead-free soldering. Solder bath temperatures up to 550°C possible.	- similar requirements as for wave soldering machines - SEHO's MWM 3250 is designed for lead-free soldering. Solder bath temperatures up to 550°C possible.	- similar requirements as for wave soldering machines - SEHO's MWM 3250 is designed for lead-free soldering. Solder bath temperatures up to 550°C possible.

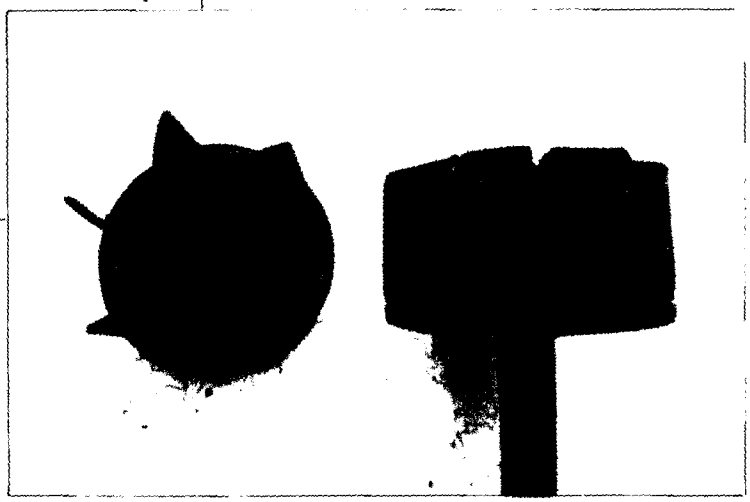


ceramic impeller wheel

Lead-Free Technology



coated impeller wheel



Lead-Free Technology

Using lead-free solders, the following additional recommendations should be followed:

1. Changing the solder alloy in an existent machine (from one containing lead to a lead-free one) the solder bath must be absolutely clean.
   If necessary, the solderbath must be exchanged.
   SEHO generally advises to change the solder bath because of possible contamination.

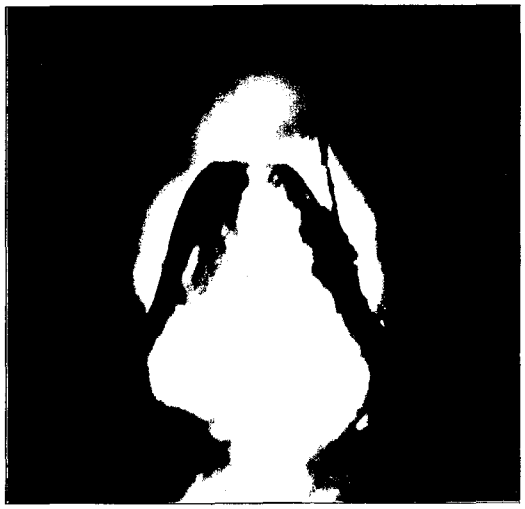
2. Components and the surface of the printed circuit board must harmonize with the new alloy.

Using lead-free solders, the following additional recommendations should be followed:

3. The fluxes must suit the process (e.g. higher temperatures etc.)
4. To change over to a lead-free solder alloy requires new definitions of the soldering process parameters. These, however, may only be established relative to the specific application and client.
   Therefore, do not hesitate to contact your local SEHO Soldering Consultant Service who will be glad to help you.

Soldering in nitrogen atmosphere offers several advantages, especially when using lead-free solders:

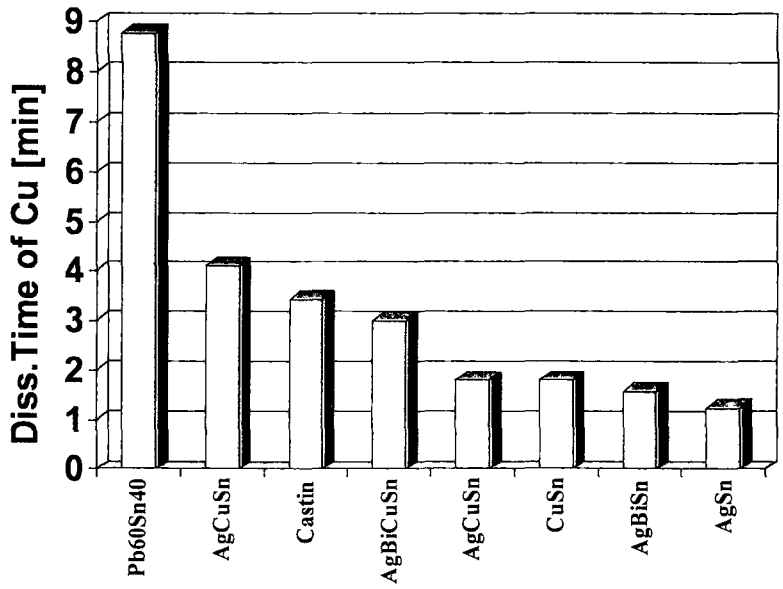
- improved wetting
- reduction of soldering temperatures
- less oxidation
- less corrosion
- less aggressive flux needed



Soiling of the solder due to leak out of iron from stainless steel elements.

temperature: 285 °C
time: 8 hours
alloy: SnAgCu

Example: Extraction of Cu



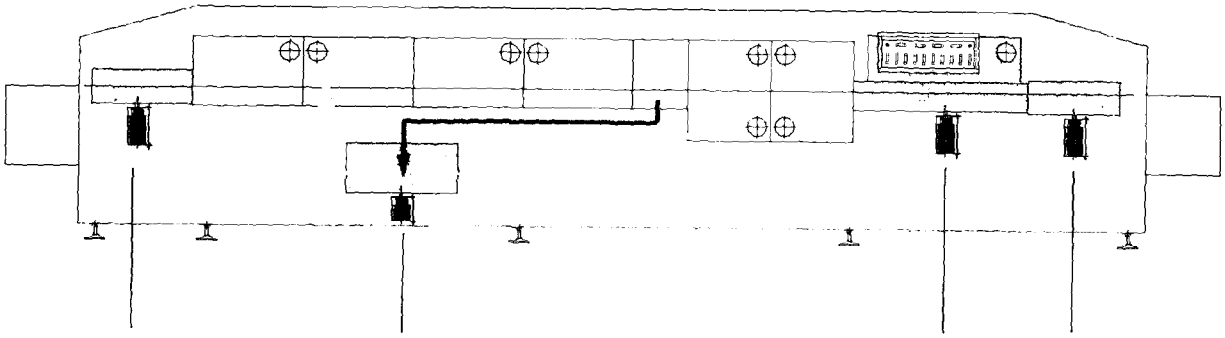
Values for Reflow Soldering

- time above liquidus (T_L)
  - diffusion area < 2 µm ??
  - < 60 seconds
- glassy point T_g
  - components are more critical
- shoulder
  - depending on ΔT

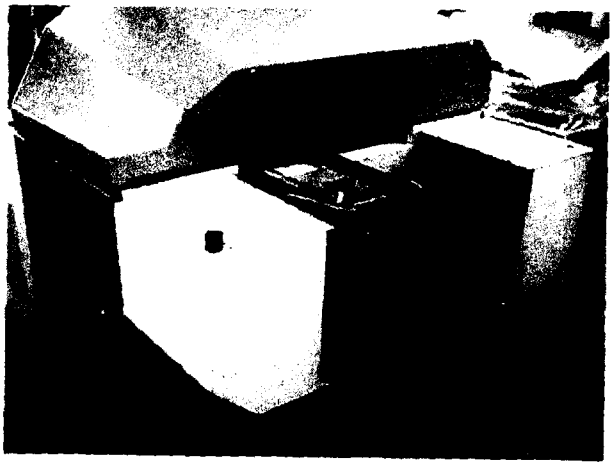
Reflow Soldering Systems

- throughput: length of machine
- gas temperature ⇨ bearings / motors
- peak temperature
- ΔT and soak time
- efficiency of heat transfer

Lead-Free Technology

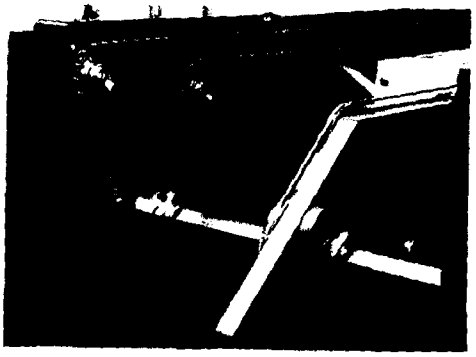


Lead-Free Technology

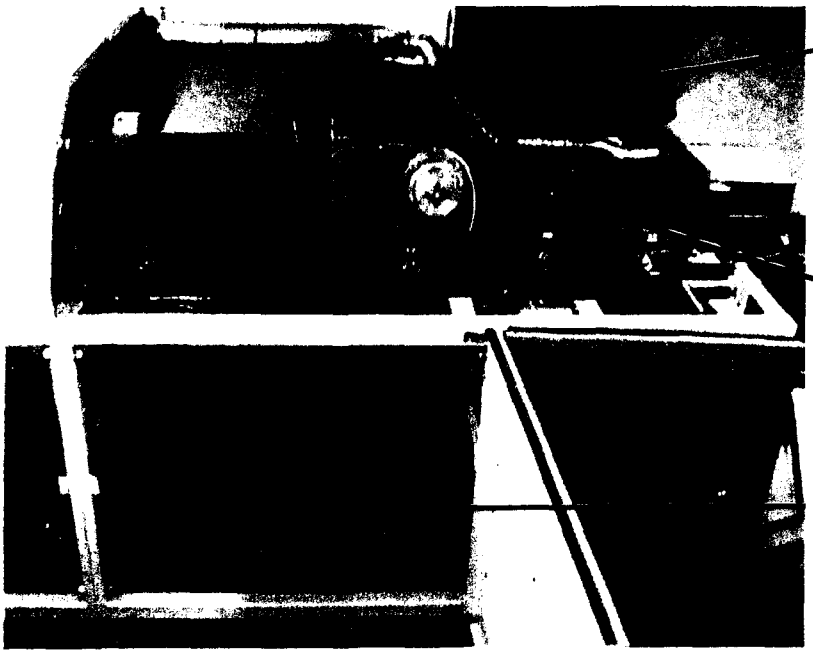


Center Support:

- rope with diameter of 2 mm
- electrical adjustment of height and width position (optionally via PC)
- large clearance possible



Lead-Free Technology

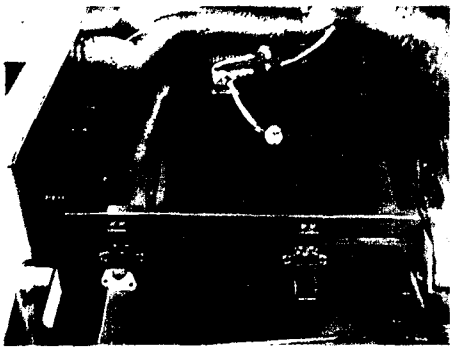


active cooling zone

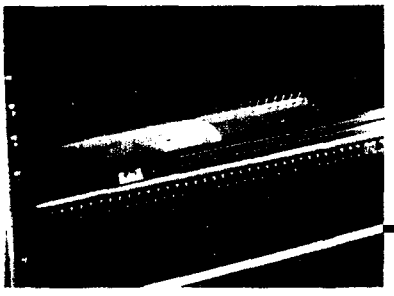
multi-functional cooling tunnel

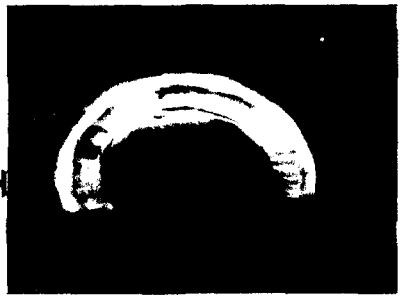
cooling aggregate

Lead-Free Technology



- oxygen barrier
- stabilization of the process atmosphere
- condensation trap:
  resídues condense at the cooling grips and flow through the opening into provided bottles

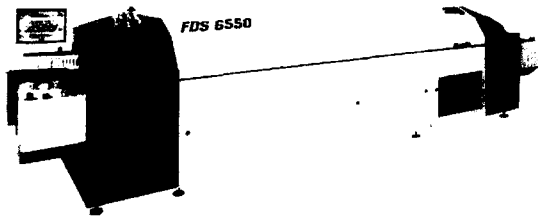




SEHO Reflow Soldering Systems

Test Results

tin-silver-copper Sn95Ag4Cu mp: 217°C	tin-silver Sn96Ag4 mp: 221°C	bismuth-tin Bi57Sn43 mp: 138°C
increased oxidation consequently nitrogen atmosphere recom-mendable	increased oxidation consequently nitrogen atmosphere recom-mendable	standard machine



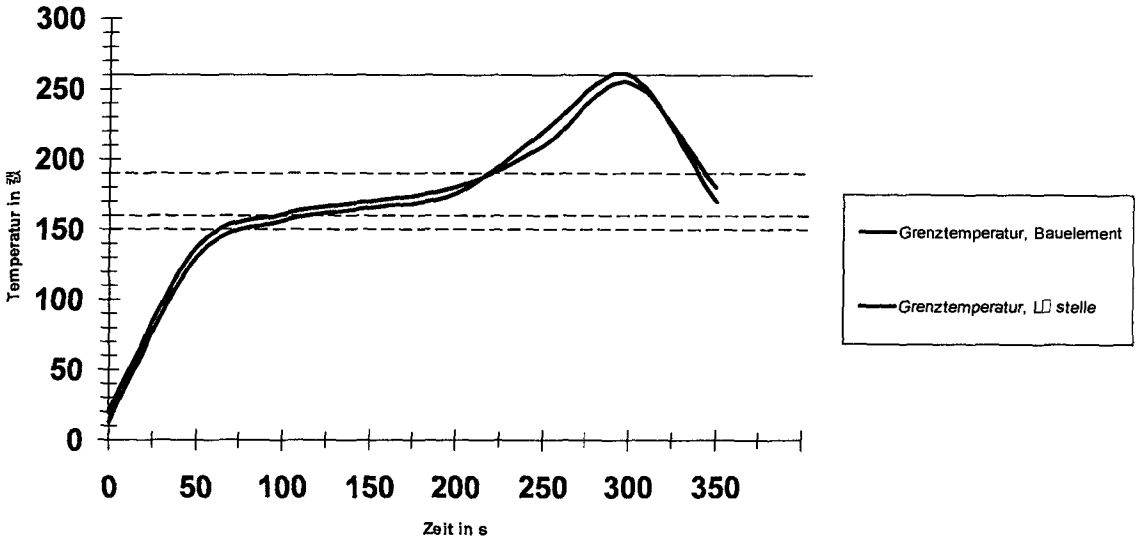
ZVEI - temperature profile (based on specification for components)

heating gradient:	1 - 3 K/s
soak temperature:	160 °C + 30 °C - 10 °C
soak time:	20 - 120 s
time above liquidus:	20 - 80 s
peak temperature:	260 °C
time above peak:	mind. 10 s
cooling gradient:	2 - 5 K/s

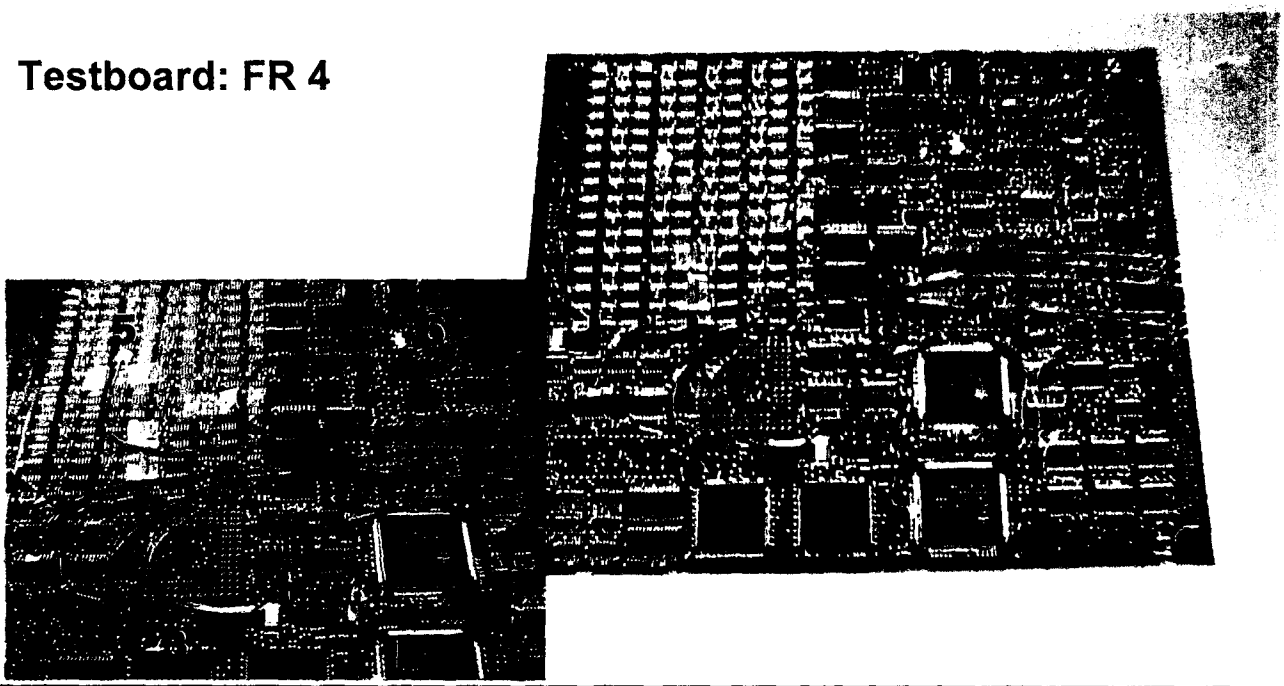
Exception: Area Array BE (> 200 I/O, Pitch ≥ 1 mm)

peak temperature:	240 °C
time above peak:	10 - 20 s

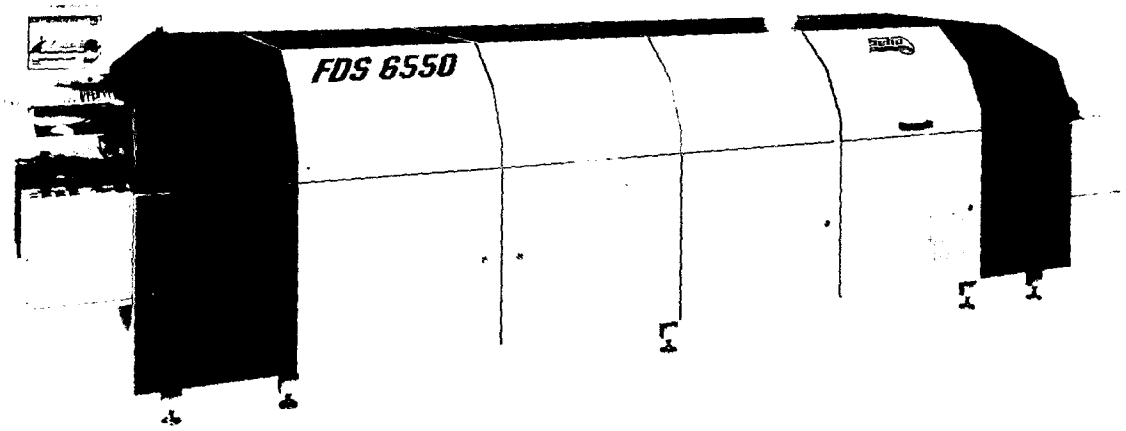
ZVEI proposal for reflow temperature profile "lead-free"



Testboard: FR 4

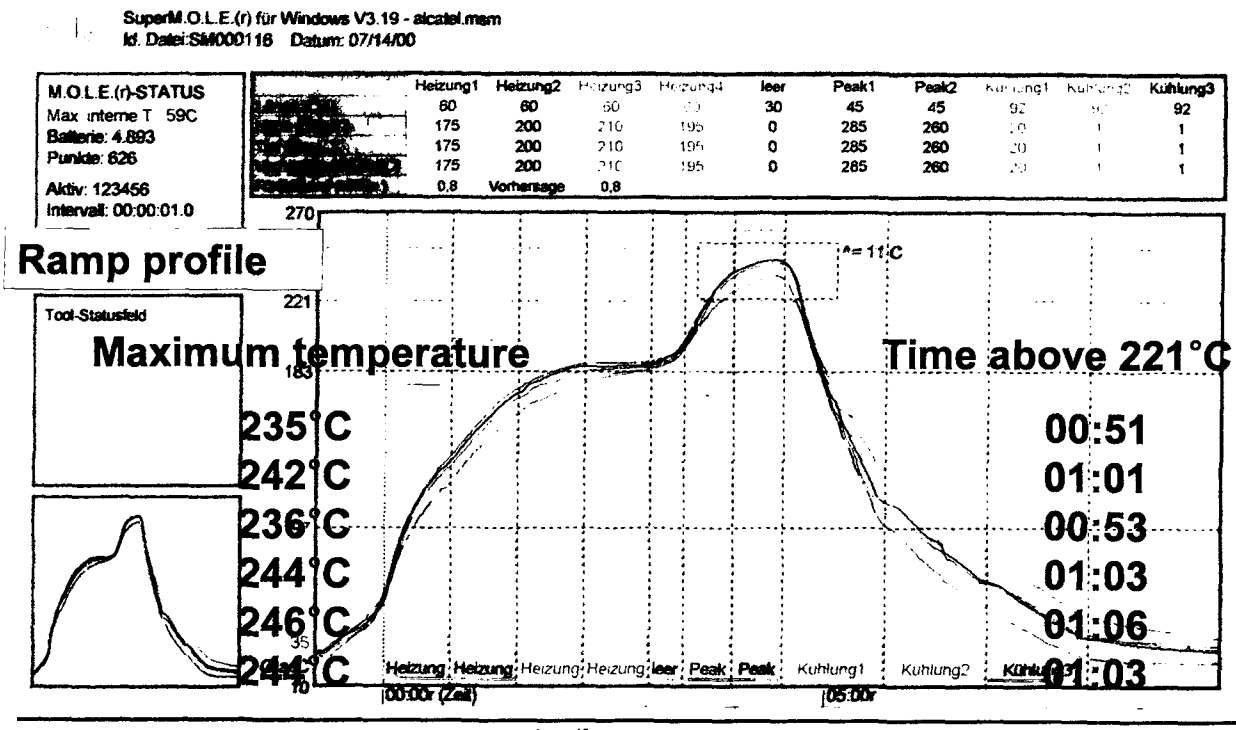


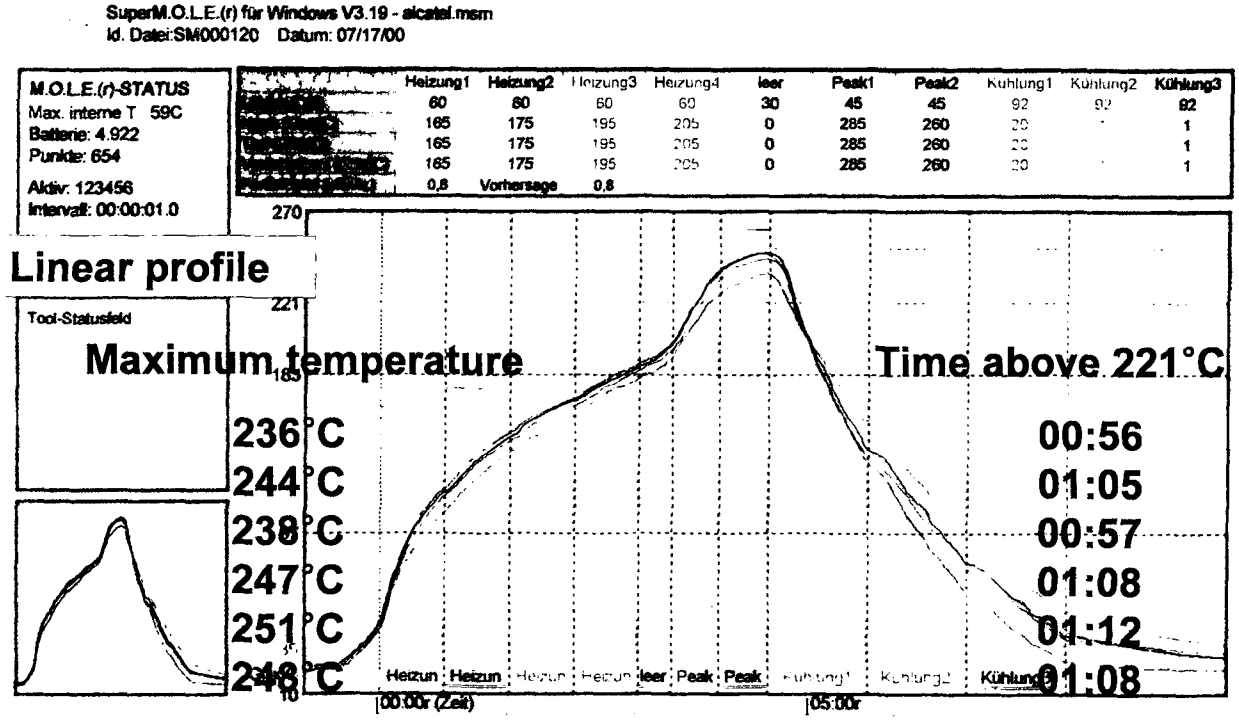
Test Machine: FDS 6550/3.6



In General:

- The machine can withstand the higher temperatures which will be required by lead-free solders without any problem
- The tests are based on a solder paste having the melting point at 221°C
- Alternatively two profiles were run:
  - standard ramp profile
  - linear profile


SuperM.O.L.E.(r) für Windows V3.19 - alcatel.msm
Id. Datei:SM000116 Datum: 07/14/00
M.O.L.E.(r)-STATUS
Max. interne T 59C
Batterie: 4.893
Punkte: 626
Aktiv: 123456
Intervall: 00:00:01.0
Heizung1 Heizung2 Heizung3 Heizung4 leer Peak1 Peak2 Kühlung1 Kühlung2 Kühlung3
60 60 60 60 30 45 45 92 92 92
175 200 210 195 0 285 260 1
175 200 210 195 0 285 260 1
175 200 210 195 0 285 260 1
0,8 Vorhersage 0,8
Ramp profile
Tool-Statusfeld
Maximum temperature
Time above 221°C
235°C 00:51
242°C 01:01
236°C 00:53
244°C 01:03
246°C 01:06
244°C 01:03
Δ= 11°C
270
221
183
35
10
Heizung Heizung Heizung Heizung leer Peak Peak Kühlung1 Kühlung2 Kühlung3
00:00r (Zeit)
05:00r


SuperM.O.L.E.(r) für Windows V3.19 - alcatel.msm
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M.O.L.E.(r)-STATUS
Max. interne T 59C
Batterie: 4.922
Punkte: 654
Aktiv: 123456
Intervall: 00:00:01.0
Heizung1 Heizung2 Heizung3 Heizung4 leer Peak1 Peak2 Kühlung1 Kühlung2 Kühlung3
60 80 60 60 30 45 45 92 92 92
165 175 195 205 0 285 260 1
165 175 195 205 0 285 260 1
165 175 195 205 0 285 260 1
0,8 Vorhersage 0,8
Linear profile
Tool-Statusfeld
Maximum temperature
Time above 221°C
236°C 00:56
244°C 01:05
238°C 00:57
247°C 01:08
251°C 01:12
248°C 01:08
270
221
185
35
10
Heizung Heizung Heizung Heizung leer Peak Peak Kühlung1 Kühlung2 Kühlung3
00:00r (Zeit)
05:00r

PCB Surfaces

- HAL (Hot Air Leveling)
- chemical tin
- chemical silver (with organic protection)
- nickel / gold
- OSP (Organic Solderability Protection)

Elimination of halogenated flame obstructors

Availability

- ➔ several japanese companies offer adequate products
- ➔ Toshiba, Hitachi, Sumitomo
- ➔ several european companies also offer products

Alternative flame obstructors: organic-phosphorus combinations

- ➔ compatible with epoxy resin
- ➔ can be mixed with epoxy resins or reacts
- ➔ comperatively hydrophone
- ➔ more expensive than Br-FR's, i.e. TBBA

Lead-Free Technology

Chemical (Electroless) Tin	
Characteristics:	➔ Thickness 1 µm (40 µ") - 1.3 µm (50 µ") max. ➔ Purity: 99.9x % tin typically
Advantages • Low thermal stress • Even coverage • Easy process control • Small effects on environment • Acceptable machine- and process costs • Storage time: 12 months (correct storage) • Multi-pass solderability • Thin oxyde layers with no-clean flux • Good wettability with no-clean flux • Good compatibility with lead-free solder • Advantages for press-in technology • Planarity for fine pitch components • Reliable connections directly on Cu	**Disadvantages** • Cu reduction by 1 µm (exchange reaction Cu vs. Sn) • Limited thickness (exchange reaction...) • Rework not possible • Selected surfaces (e.g. gold) must be covered • Little experience of the PCB producers • Wire bond not possible
Comments:	➔ Small market share ➔ Increasing interest

Lead-Free Technology

Chemical (Electroless) nickel / gold	
Characteristics:	➔ Thickness Ni: 3 µm (120 µ")...7 µm (275 µ") Au: 0.05 µm (2 µ")...0.15 µm (6 µ")
Advantages • Low thermal stress • Even coverage • Small effects on environment • Storage time: 12 months (correct storage) • Multi-pass solderability • Good wettability with no-clean flux • Good compatibility with lead-free solders • Press-in technology possible • Planarity for fine pitch components • Wire bond possible • Very good protection of non-soldered areas	**Disadvantages** • Cu reduction when cleaning etc. by 1 µm • Limited thickness (exchange reaction Au/Ni) • Rework not possible • Selected surfaces (e.g. gold) must be covered • Sensitive against scratches • Great expenditures for process control • High machine- and process costs • Critical reaction with water: Ni corrosion! • Solder joint not directly on Cu
Comments:	➔ High market share in case of high-end products

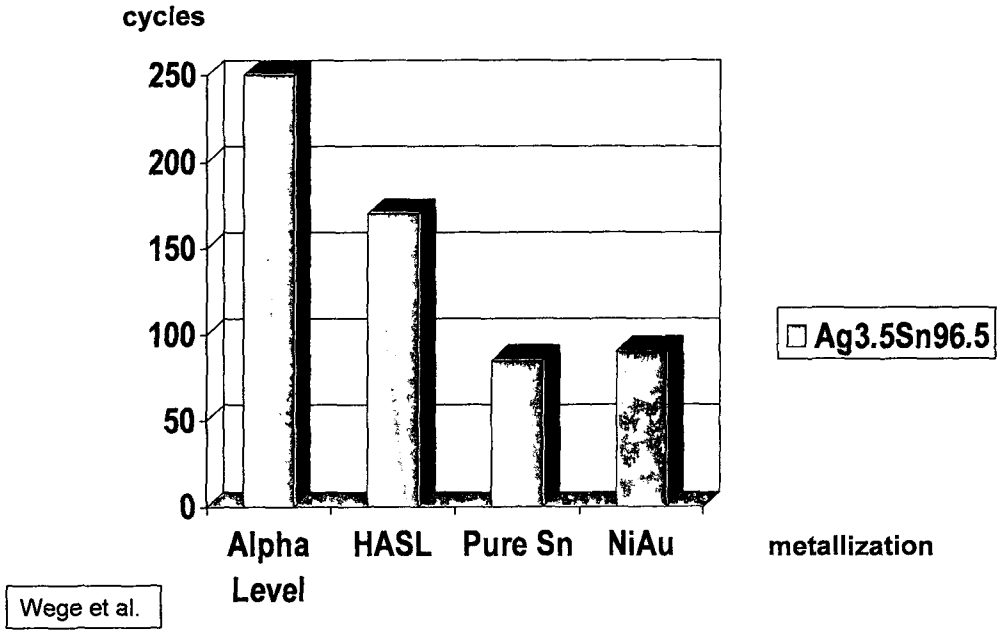
Lead-Free Technology

Organic Surface Protoction (OSP) / Organic Copper Coat (OCC)	
Characteristics	➔ Thickness: 0.2 µm (8 µ")...0.3 µm (12 µ")
Advantages • Low thermal stress • Even coverage • Small effects on environment • Storage time: 6 – 12 months (correct storage) • Multi-pass solderability • Good wettability with no-clean flux • Good compatibility with lead-free solders • Press-in technology possible • Planarity for fine pitch components • No Cu reduction • Multiple re-coating possible • Some OSPs; selected surfaces (e.g. gold) do not require coverage • Easy process control • Low machine and process costs • Robust against scratches • Press-fit possible • Direct solder joint on Cu	**Disadvantages** • Electric contact not possible • Fine adjustment of flux required • (?) Multi-pass soldering at higher temperatures needs to be prooved (N2) • Wire bond not possible • Long-term protection of non-soldered areas (connector application not possible)
Comments:	➔ High market share ➔ Japanese manufacturers develop hi-temp OSP

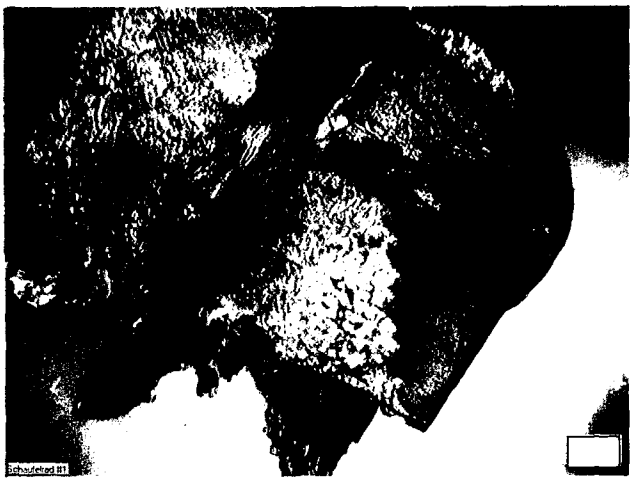
Lead-Free Technology

	Comparison: Surfaces	tin	Silver	NiAu	OSP
PCB manufacturing	Thermal stress				
	High aspect ratio coverage				
	E-O rework	no	no	no	
	Costs	neutral	neutral	high	
ASM manuf.	Storage	neutral	neutral		short
	Multi-pass soldering at high temperatures				neutral
Product use	Press-fit (metallurgy, variation of hole diam.)		neutral	?	neutral
	Fine pitch (surface planarity, whiskers)				
	Wire bonding (metallurgy)	no	neutral		no
	Long-term protection of non-soldered areas	neutral	neutral		limited

LCCC-84 Solder Joint Deficit

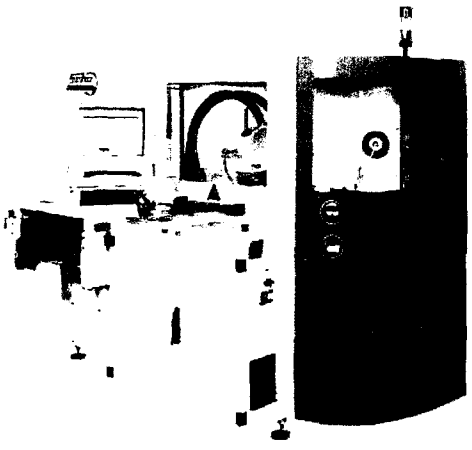


Wege et al.



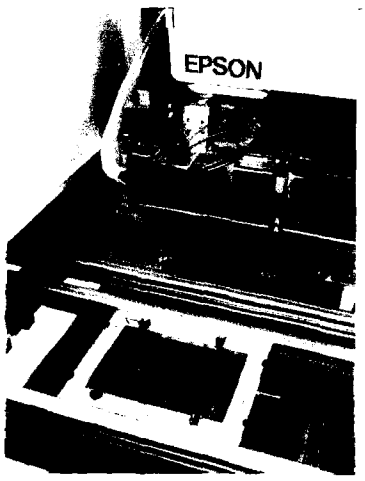
Lead-Free Technology

Lead-Free Technology



Miniwave System

MWM 3250



Reflow - System

FDS 6500