The Development of a Qualification Temperature Profile for Lead-Free Reflow Soldering and the Influence of the Peak Width on the Semiconductor Devices

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Cooperation of the European Automotive Electronic OEMs:

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Hella KG Hueck & Co - Lippstadt
Robert Bosch GmbH - Stuttgart
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Outline:

The Development of a Qualification Temperature Profile for Lead-Free Reflow Soldering

- Prerequisites and general Requirements
- Test Board Design
- Tolerances
- Peak Form and Width
- Measured Temperatures
- Device Classes
- The Qualification Profile

The Influence of the Peak Width on the Semiconductor Devices

- Description of the performed Experiment
- Reflow Profiles
- SAM Results

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Qualification Temperature Profile for Lead-Free Reflow Soldering

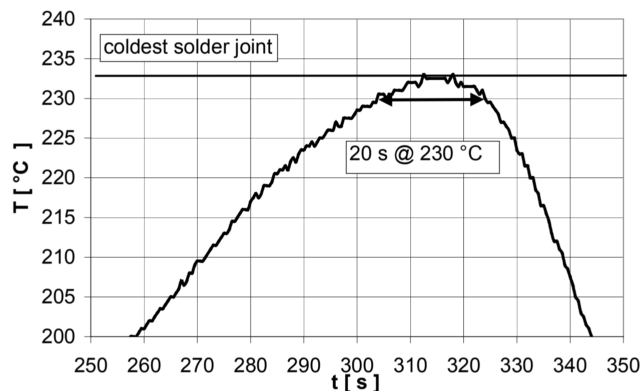
Temperature and Time Requirements at Coldest Solder Joint

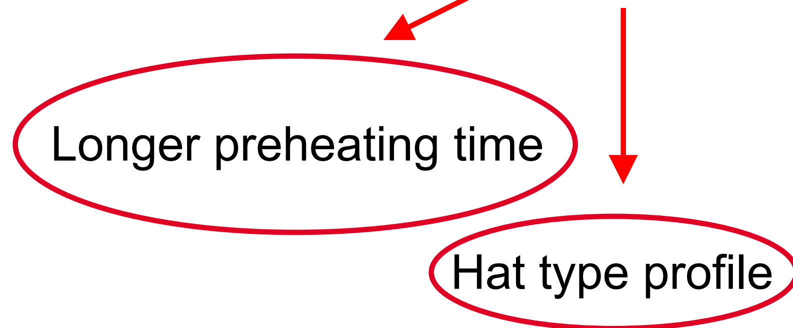
- General requirement to achieve a reliable solder joint, while reducing the heat impact on the components and the printed circuit board:

⇒ **minimum 20 s @ 230 °C (corresponds to 1 s @ 233 °C)**

- Comparison between SnPb and SnAgCu technology:

SnPb:	T_{liquid} = 183 °C	T_{min} = 203 °C	ΔT = 20 K
SnAgCu:	T_{liquid} = 217 °C	T_{min} = 230 °C	**ΔT = 13 K**





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Equipment and Automotive Mass Production Conditions

- Moderate range of package sizes on typical board
- Transportation speed:
  realistic production line speed of 850 mm/min (33 inch/min)
- Reflow soldering equipment:
  only 4 of 7 reflow furnace suppliers are able to fulfill the requirements for the T-profile with full convection, > 10 zone furnaces, N_2 atmosphere (status 2003)

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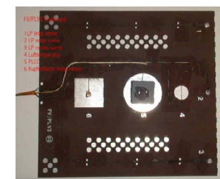
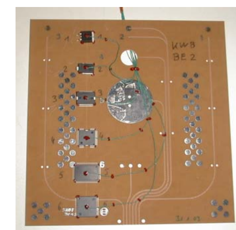
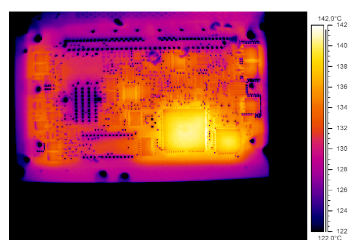
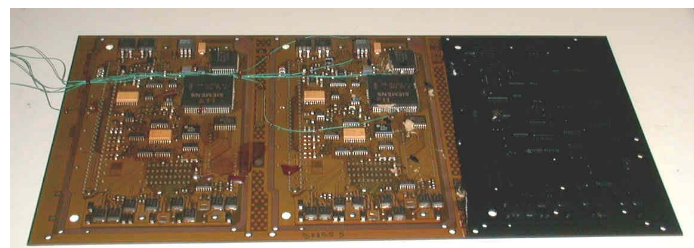
Test Board Design

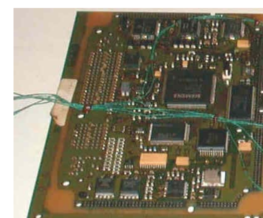
- Material: Polyimide resin (T_g: 260 °C)
- 6 measuring points on each type of board
  - type I board: coldest solder joint + 5 x PCB surface
  - type II board: 6 x on top of device package
- Coldest solder joint:
  - coldest solder joint on test board represents the coldest solder joint on serial boards (thermal mass)
  - definition by measurements on serial boards using thermographic methods and experience











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Tolerances of Temperature Measurement and Furnace

Temperature measurement:

- Temperature measurement done central on top of the packages
- Selected thermocouples (NiCrNi)
- Standardized preparation of thermocouples

- Measurement and preparation accuracy

Thermocouples with evaluation unit:	± 1.0 K
Assembly of thermocouples (best case):	± 0.5 K

Tolerance of temperature measurement: $\Delta T_{meas} = \pm 1.5$ K

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Tolerances of Temperature Measurement and Furnace

- Consideration of process tolerances necessary for serial production of automotive products

  Furnace tolerances:

  State of furnace loading (min. / max. loading): **± 0.5 K**

  Long term stability (5 σ tolerance): **± 2.5 K**

  Total tolerance of temperature measurement and furnace:

  Gaussian error propagation theorem possible (independent tolerances):

Loading of the furnace:	± 0.5 K
Long term stability of the furnace:	± 2.5 K
Temperature measurement ΔT_{meas}:	± 1.5 K

Tolerance of measurement and furnace: $\Delta T_{mf} = \pm 3.0$ K

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Temperature Correction based on Test Board Design

- Longitudinal temperature profile dependent on test board design (**lowest** temperature in the middle of the board)
- Transverse temperature profile according to furnace suppliers
- Thermal mass (coldest solder joint) on test board includes both temperature corrections
- For upper tolerance of temperature window both corrections have to be considered

Transverse temperature correction:	+ 2.0 K
Longitudinal temperature correction:	+ 1.5 K

Temperature correction dep. on position: ΔT_{pos} = + 2.0 to 3.5 K

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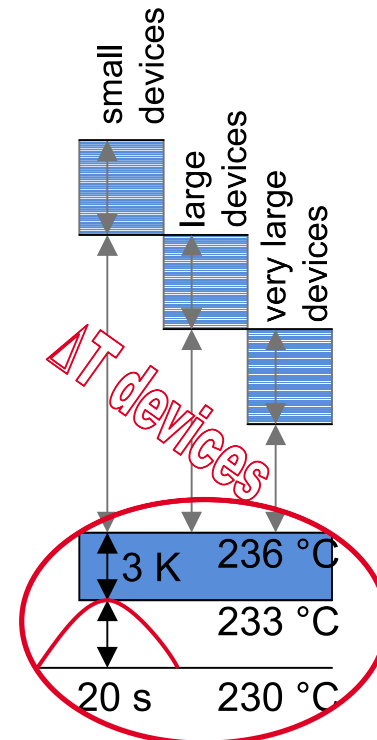
Qualification Temperature Profile for Lead-Free Reflow Soldering

Addition of Board and Process Tolerances

- Starting point: 20 sec @ 230 °C, i. e.1 s @ 233 °C based on experience and measurements
- Test board and furnace tolerances

➡ **Due to $\Delta T_{mf} = \pm 3.0$ K, the furnace has to be adjusted 3 K higher!**

➡ **Coldest solder joint has to be profiled at 236 °C!**



- Temperature split of devices
- position dependent upper tolerance

➡ $\Delta T_{mf} + \Delta T_{pos}$ **= 5 K to 6.5 K**

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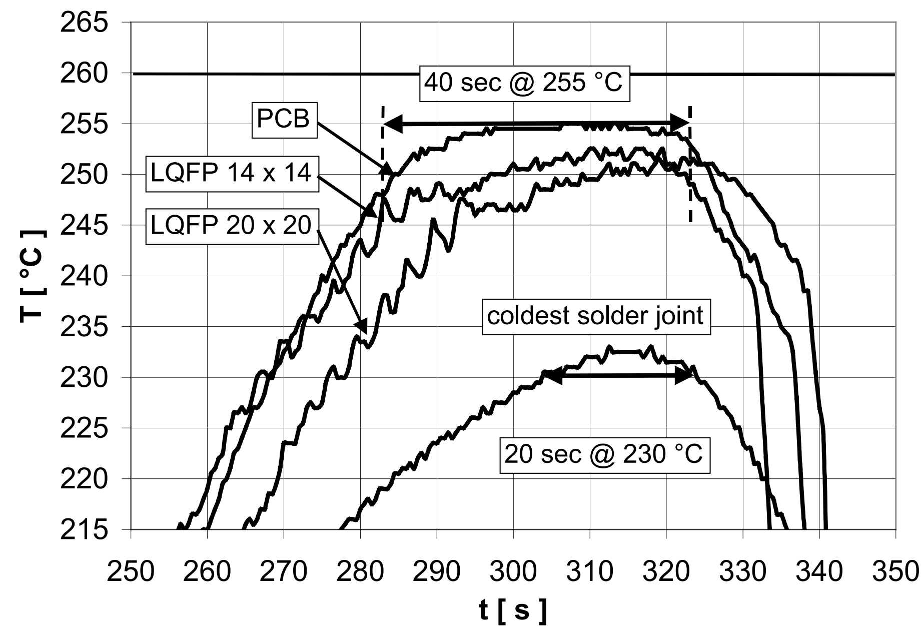
Qualification Temperature Profile for Lead-Free Reflow Soldering

Peak Form and Width: Device Classification (Small Components < 260 °C)

- Hat type profile necessary to obtain:
  - coldest solder joint 20 s @ 230 °C
  - small components $T_{Peak} \leq 260$ °C

- Necessary times t @ T_{Peak} - 5 K:

T_{Peak}	260 °C
t@T_{Peak}-5K	40s@255°C
T_{Peak}	250 °C
t@T_{Peak}-5K	30s@245°C
T_{Peak}	245 °C
t@T_{Peak}-5K	30s@240°C



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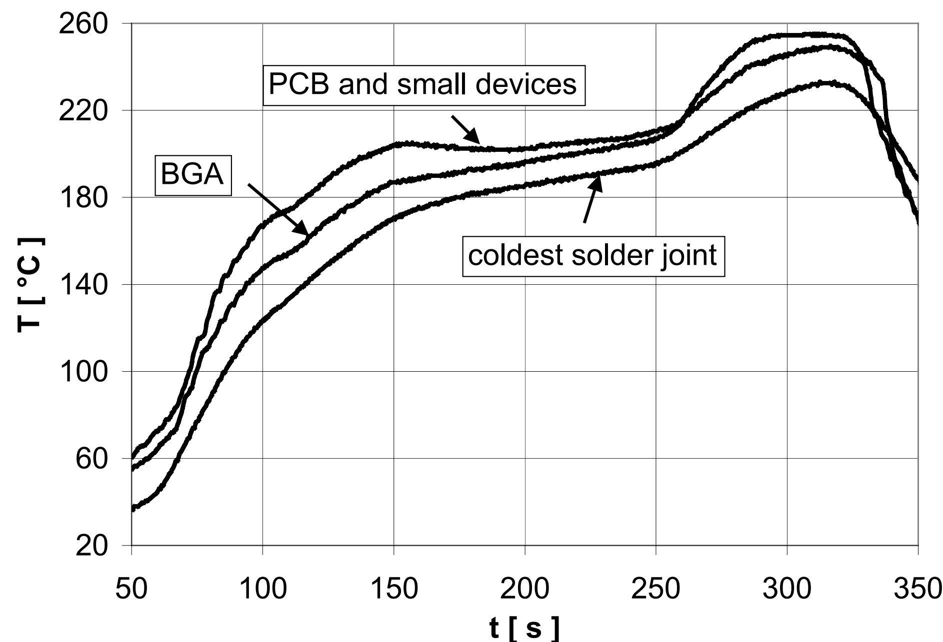
Qualification Temperature Profile for Lead-Free Reflow Soldering

Measurements using Test Board

- Investigation of 20 different packages including tolerances
- All thermocouples mounted on top of the packages (central)
- Transportation speed: 850 mm/min (33 inch/min)



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Qualification Temperature Profile for Lead-Free Reflow Soldering

Peak Temperatures of Devices

- Measured values and final values with tolerances
- Tolerances:
  $\Delta T_{mf} = \pm 3.0$ K
  $\Delta T_{pos} = + 2.0$ to 3.5 K
- 3 classes of devices
  245 °C, 250 °C, 255 °C
- Distance to coldest solder joint of measured values (Δ T):
  4 K (large devices)
  9 K (small devices)
  14 K (distance to printed circuit board)

package (measurement on top of package)	measurement	final values with tolerances
	[°C]	[°C]
coldest solder joint	233,0	236,0
PLCC 84 (30 x30)	232,5	241,0
QFP160 (28 x 28)	233,5	242,0
PLCC 68 (24 x 24)	233,5	242,5
PLCC 44 (17 x 17)	234,0	242,5
PLCC 52 (19 x 19)	234,0	243,0
DO218	236,0	244,5
MO-166	237,0	246,0
QFP-exposed pad (20 x 14)	237,5	246,0
SO28	237,5	246,0
PLCC 28 (12 x 12)	238,0	246,0
QFP144 (28 x 28)	237,0	246,5
MO-188 (14 x 14)	237,5	247,0
QFP80 (20x14)	238,5	247,0
TO 263	239,5	247,5
SO 44 XL	240,0	248,0
QFP 80 (14 x 14)	240,5	248,5
BGA (24 x 24)	240,5	249,5
LQFP-MS026 (20x20)	242,0	251,5
LQFP 100 (14 x 14)	243,5	252,5
temperature on pwb	247,0	255,0

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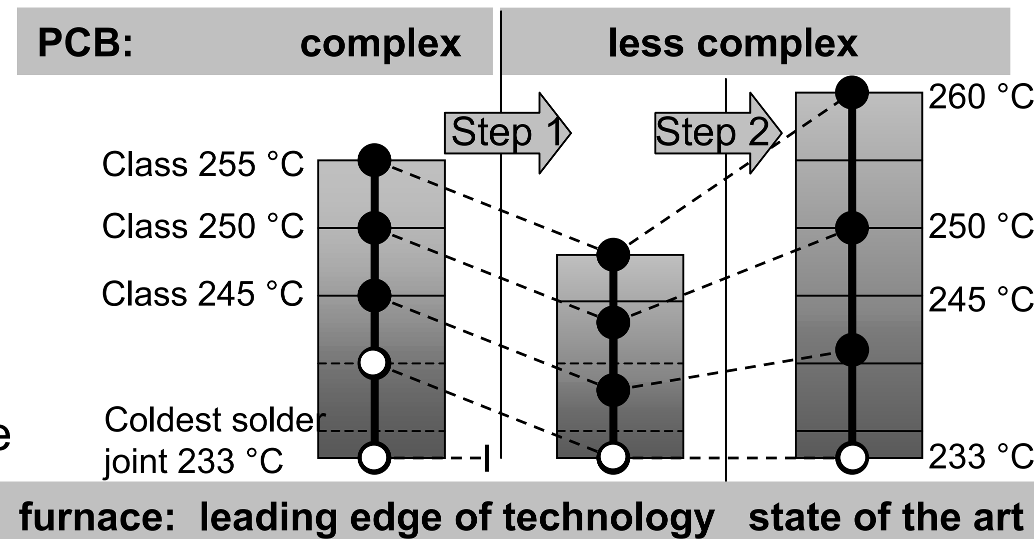
Qualification Temperature Profile for Lead-Free Reflow Soldering

Peak Temperature 260 °C for small Components

- Benefit of qualifying at 260 °C: Less complex boards can be soldered on state of the art reflow furnaces (actual equipment)
- Qualification of small devices at 260 °C is very common, other devices will stay in their class (250 °C, 245 °C).

Step 1:
Reduction of Δ T due to less complexity of the board

Step 2:
Enlargement of Δ T between devices be-cause of change to state of the art furnace (less powerful furnace)



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Qualification Temperature Profile for Lead-Free Reflow Soldering

Peak Temperature: Device Classification

- From a physical point of view the heat capacity and heat conductivity should be the measure for device classification

- But volume and thickness are taken for simplification reasons. This is possible for devices with similar composition (molded components)

thickness\volume	< 350 mm³	350 - 2000 mm³	> 2000 mm³
< 1,6 mm	260 (- 0) °C	260 (- 0) °C	260 (- 0) °C
1,6 - 2,5 mm	260 (- 0) °C	250 (- 0) °C	250 (- 0) °C
> 2,5 mm	250 (- 0) °C	250 (- 0) °C	245 (- 0) °C

- Due to repair reasons all BGAs 260 °C

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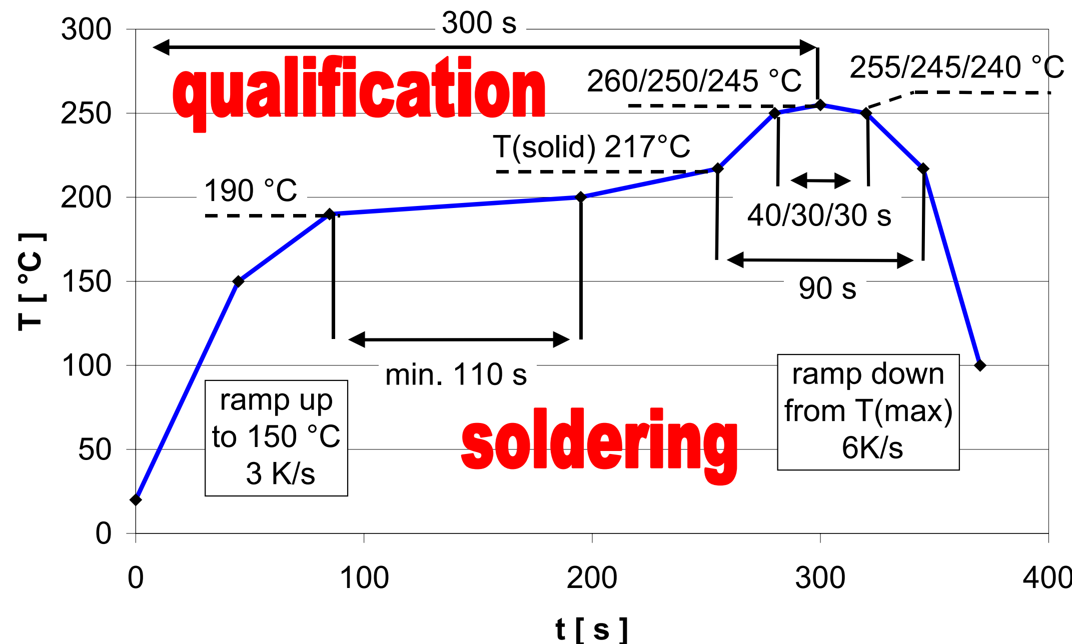
Qualification Temperature Profile for Lead-Free Reflow Soldering

Lead-free Reflow Temperature Profile for MSL Classification (Figure)



- **Qualification profile** with minimum values for temperatures, times, ramp up and ramp down rates. Devices have to be soldered at least 3 times
- The shown graph represents the limiting line between suppliers and manufacturers

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Qualification Temperature Profile for Lead-Free Reflow Soldering

Lead-free Reflow Temperature Profile for MSL Classification (Table)

Profile Features	Small Devices	Large Devices	Very Large Devices
preheat			
ramp-up rate to 150 °C	min. 3 K/s (average value over 10 s)		
time from 190°C to 200°C	min. 110 s		
peak			
ramp-up rate from 200°C to T_{peak}	0,5 K/s - 3 K/s (average value over 10 s)		
time above $T_{solidus}$ (min. 217 °C)	min. 90 s		
peak temperature T_{peak}	260 (- 0) °C	250 (- 0) °C	245 (- 0) °C
time above T_{peak} - 5 K	min. 40 s	min. 30 s	min. 30 s
cooling			
ramp-down rate from $T_{solidus}$ (min. 217	min. 6 K/s (average value over 10 s)		
general			
time 25 °C to T_{peak}	min. 300 s		

- Qualification profile with min. values for temperatures, times and ramps
- Device qualification temperature profile at the component supplier has to stay above these values, while during soldering the electronic assembler has to stay below these values

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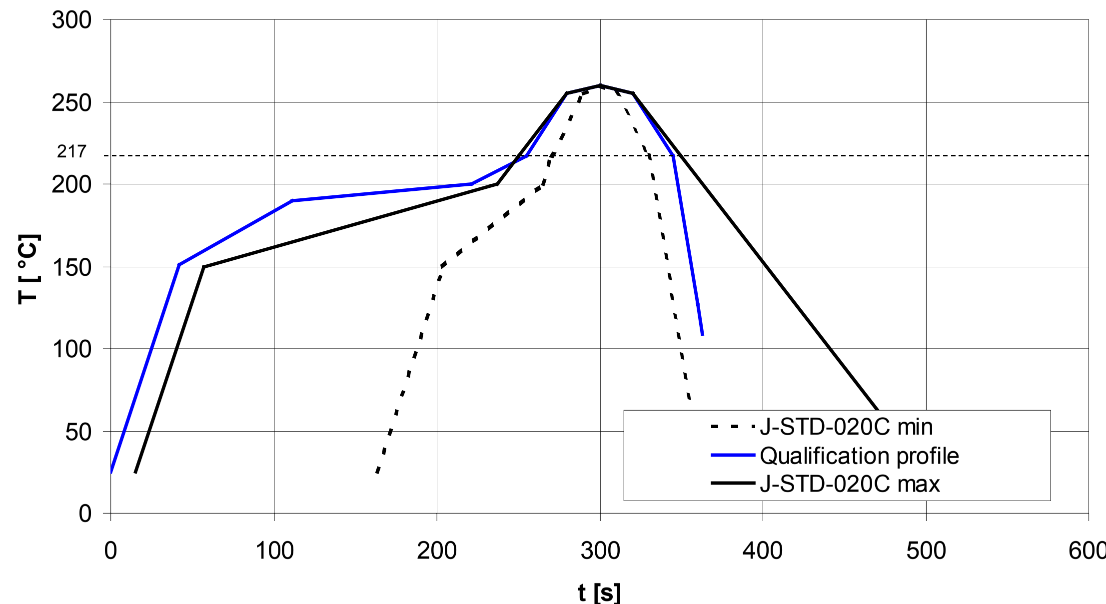
Qualification Temperature Profile for Lead-Free Reflow Soldering

Comparison between presented Qualification Profile and J-STD-020C



- Devices qualified according to J-STD-020C max will presumably pass the proposed qualification profile
- Qualification according to J-STD-020C min is not sufficient for real assembly processes

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Description of the performed Experiment

- Investigated samples: LQFP100, LQFP64, TSSOP 38
  (3 different suppliers, different mold compounds, qualified or in qualification for lead-free process)
- Preconditioning for MSL = 3 (drying: 24 h / 125 °C, moisture soak: 192 h / 30 °C / 60 % relative humidity)
- 1 x reflow soldering with different peak widths: 10 s, 20 s, 30, 40 s
  (30 devices each)
- SAM (scanning acoustic microscopy)

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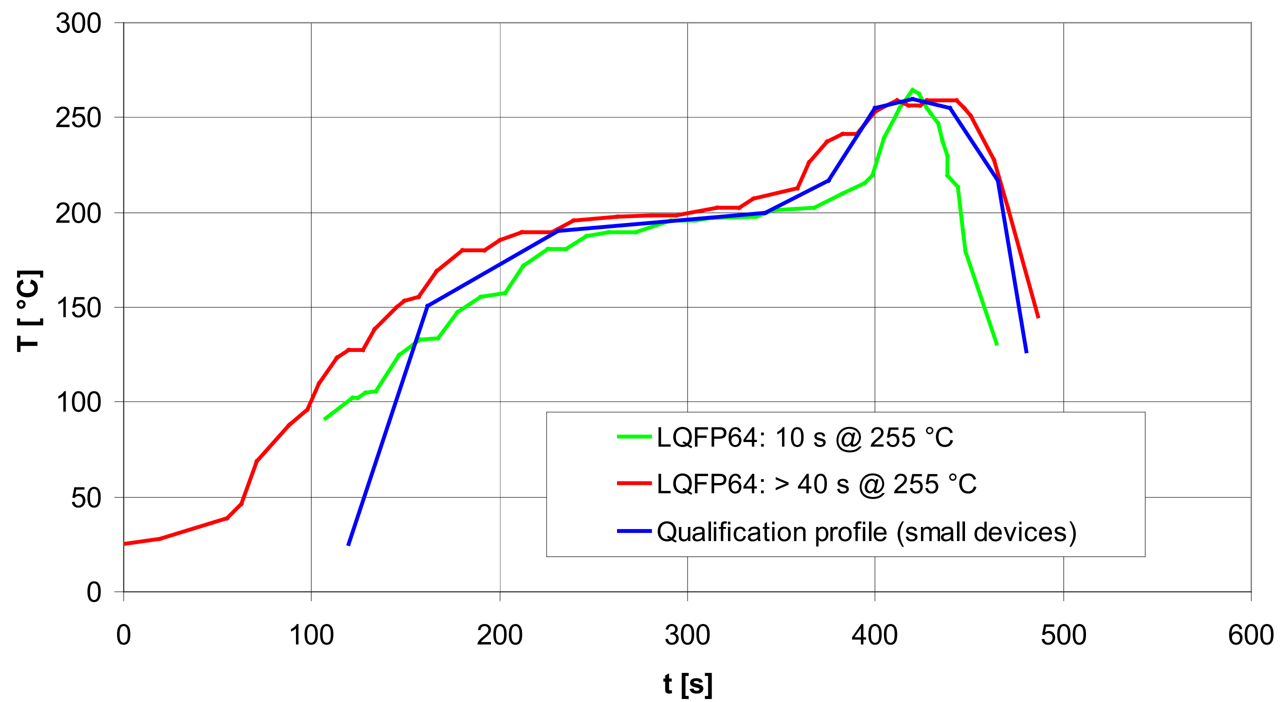
Influence of the Peak Width on the Semiconductor Devices

Reflow Profiles



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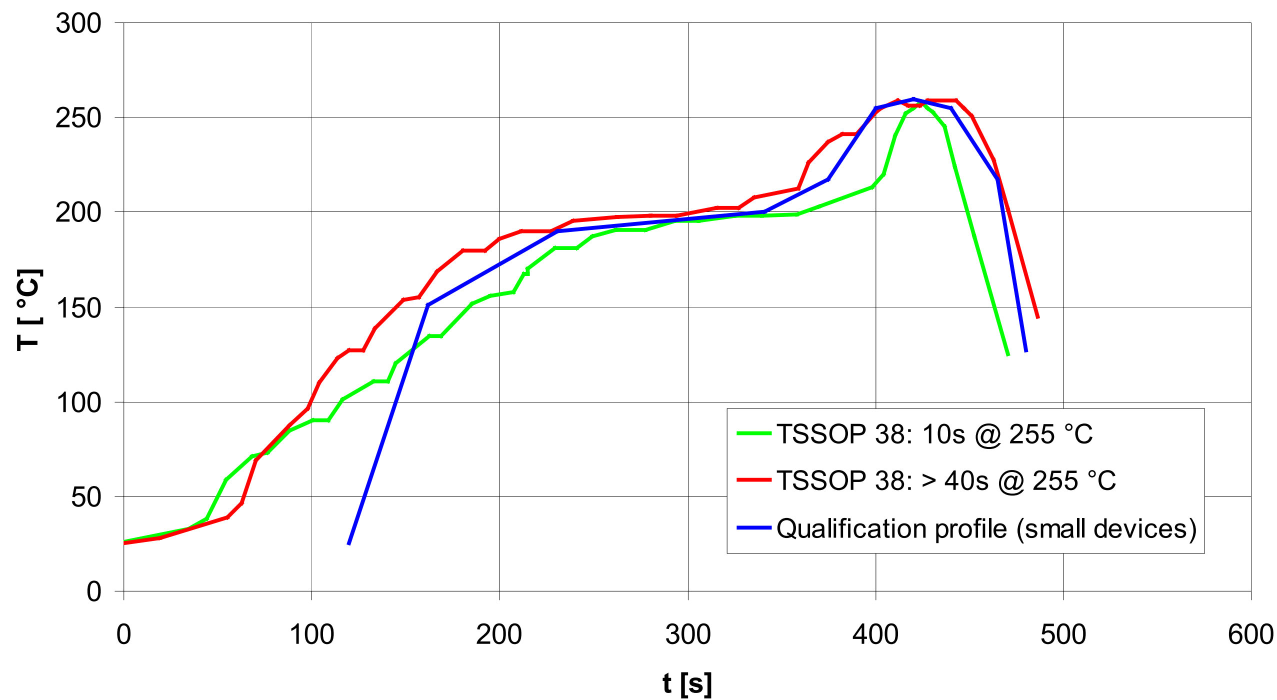
Influence of the Peak Width on the Semiconductor Devices

Reflow Profiles



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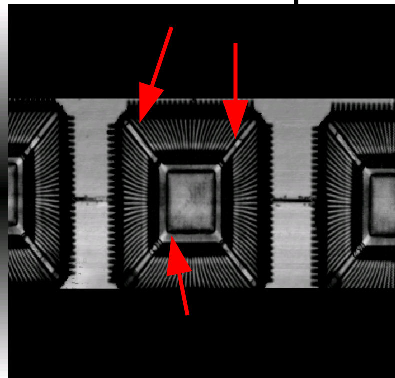
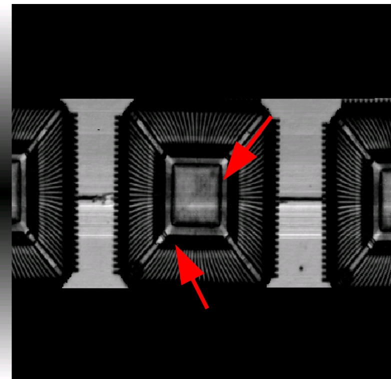
Influence of the Peak Width on the Semiconductor Devices

SAM Results: LQFP100

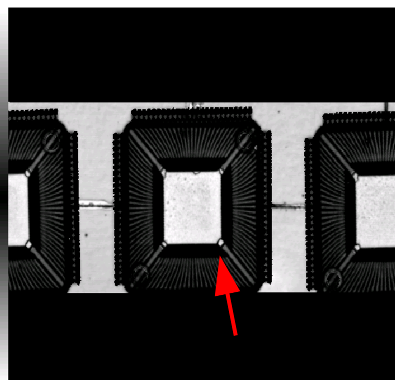
Top side: complete delamination of the die paddle;
tie bar shows partial delamination (not critical)



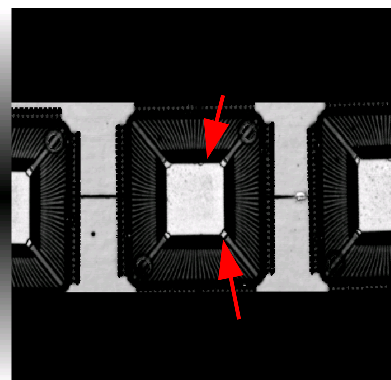
T_{peak}: 260.0 °C
t@255 °C: 9 s



Bottom side: partial delamination of the die paddle (not critical)



T_{peak}: 260.0 °C
t@255 °C: 45 s



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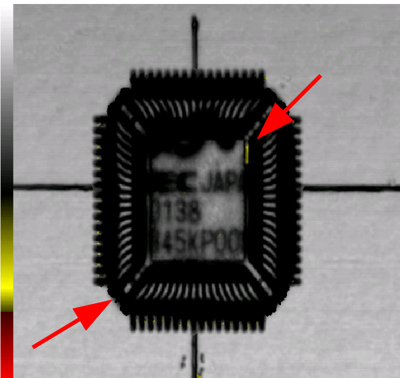
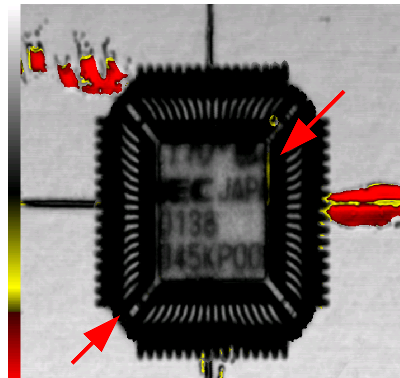
Influence of the Peak Width on the Semiconductor Devices

SAM Results: LQFP64

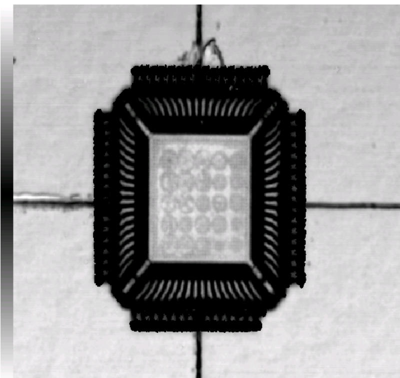
Top side: Partial delamination of the die paddle and tie bar (not critical)



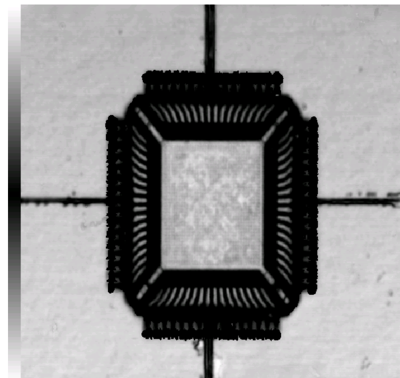
T_{peak}: 261.5 °C
t@255 °C: 12 s



Bottom side: no delaminations found



T_{peak}: 259.5 °C
t@255 °C: 41 s



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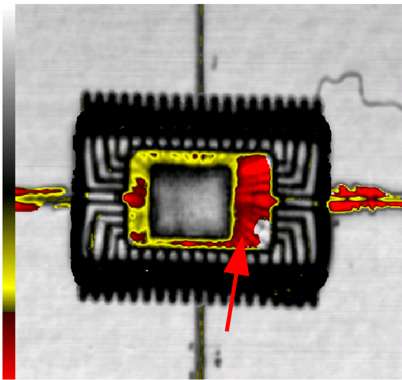
Influence of the Peak Width on the Semiconductor Devices

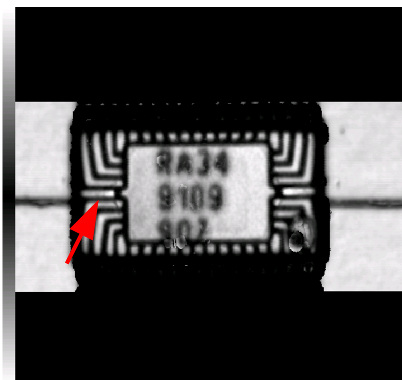
SAM Results: TSSOP 38

Top side: Complete delamination of the die paddle and tie bar (not critical)

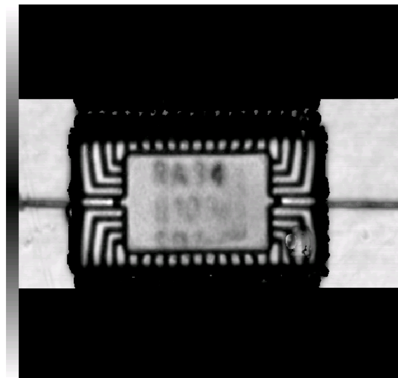


T_{peak}: 259.5 °C
t@255 °C: 9.5 s

Bottom side: partial delamination of some leadframe fingers (not critical)



T_{peak}: 260.0 °C
t@255 °C: 45 s



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Conclusions

- **Qualification temperature profile was developed to cover automotive requirements concerning reliability of the solder joint**
- **Using presented limiting profile prevents devices from harmful, unexpected stress during real, also non-automotive assembly processes**
- **No influence of the peak width on the delamination of the semiconductors was found**
- **Influence of temperature gradient during ramp up and ramp down on the delamination and reliability of the devices should be investigated**
- **Similar investigations for passive, non-molded devices are necessary**

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