IMPROVING THE QFN BOARD LEVEL RELIABILITY USING LOW MELTING TEMPERATURE LMPA-Q SOLDER

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SOLDER ALLOY HISTORICAL ROADMAP

SnPb soldering  →  SnAgCu soldering 305, 405, 387, ...

2006

• RoHS legislation

2010-Now

• Cost
• Reliability issues due to brittle fractures of too stiff SnAgCu solders
• Need for lower melting temperature

Gen. 1

Gen. 2

Better mechanical shock performance, lower alloy cost, less copper dissolution of plated through holes, less solder joint or laminate failure during board bending

Sn100C (SnCu)  →  Sb/Bi/Ag
SACX (0307)  →  SAF-A-LLOY (Sn97Ag0.2Sb0.8Cu2)
SCAN-Ge

Gen. 3

Better thermal fatigue resistance, better drop/shock or vibration resistance for harsh environment applications

Indalloy276 (90.6Sn3.2Ag0.7Cu5.5Sb)  →  SAC-Q (SAC+Bi)
Innotol /90ISC  →  SAC-M
REL22 (Sn-Ag-Cu-Bi-X)

Gen. 4

Lower processing temperature to cope with bowing of large BGA’s & temperature sensitive components

HRL1 (OM550)  →  LMPA-Q
SBX02  →  Indalloy281

11/19/2020
SNBI BASED SOLDER ALLOY
WITH LOW MELTING TEMPERATURE

LMPA-Q – LOW MELTING TEMPERATURE SOLDER BASED ON SNBI
GENERATION 4 SOLDER ALLOY

- SnBi based low melting point alloy
- Solidus: 139°C Liquidus: 176°C
- Enhanced mechanical properties compared to SnBi(Ag)
- Eliminate problems and failures related to high temperatures used in standard lead-free processes
- Suitable for Reflow soldering, Wave soldering, Selective soldering
- Cost reduction
REFLOW PROFILE
~50°C LOWER REFLOW TEMPERATURE USING LMPA-Q

- Maximum reflow temperature can be reduced to 200°C

ASSEMBLY WITH LOW MELTING TEMPERATURE ALLOY (LMPA-Q)
VOID FORMATION

SAC305

SnBi (LMPA-Q)

Void formation QFN ground plane

LMPA-Q – LOW MELTING TEMPERATURE SOLDER BASED ON SNBI

Lower process temperatures: Why?

- Lower stress on components
- BGA warping
- LED's
- Elco's, capacitors
- Plastic body components
- ...
LMPA-Q – LOW MELTING TEMPERATURE SOLDER BASED ON SNBI

Lower process temperatures: Why?

- Lower stress on PCB
- Less Warping
- No more ‘over-TG’ related issues

REDUCED HOT TEAR & HEAD-IN-PILLOW FAILURES FOR FINE PITCH BGA COMPONENT

Fine pitch FC-BGA component (23x24 mm², 855 balls, 0.5 mm pitch)

Hot tear and HIP failures experienced after solder reflow assembly

<table>
<thead>
<tr>
<th></th>
<th>SnAg3Cu0.5</th>
<th>LMPA-Q T_{reflow} = 200°C</th>
<th>LMPA-Q T_{reflow} = 190°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of assembly failures</td>
<td>126/855</td>
<td>56/855</td>
<td>17/855</td>
</tr>
<tr>
<td>Permanent deformation after 1 x reflow</td>
<td>40 µm</td>
<td>20 µm</td>
<td>0 µm</td>
</tr>
</tbody>
</table>

ALSO POSSIBLE TO SOLDER BGA’S WITH SAC SOLDER BALLS

Figure 7. Cross-section of Sn-3Ag-0.5Cu ball and X46 solder paste assembled at 180°C.

Figure 8. Cross-section of Sn-3Ag-0.5Cu ball and X46 solder paste assembled at 190°C.

Figure 9. Cross-section of Sn-3Ag-0.5Cu ball and X46 solder paste assembled at 200°C.

Morgana Ribas, Ph.D., Anil Kumar, Divya Kosuri, Raghu R. Rangaraju, Pritha Choudhury, Suresh Telu, Siuli Sarkar, LOW TEMPERATURE SOLDERING USING SN-Bi ALLOYS, SMTA 2017

PHYSICAL PROPERTIES OF LOW MELTING TEMPERATURE ALLOY (LMPA-Q)
MECHANICAL PROPERTIES

**Elongation test**

![Graph showing elongation test results for LMPA-Q, SAC305, and Sn63Pb37.](image)

- Instron 5542
- LMPA-Q, SAC305, Sn63Pb37
- Solid wire: dia: 2mm, L: 100mm
- Elongation speed: 5mm/min

<table>
<thead>
<tr>
<th>Solder Alloy</th>
<th>Elongation Length</th>
<th>Length at Failure</th>
<th>Elongation at Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMPA-Q</td>
<td>100mm</td>
<td>146.45mm</td>
<td>46.45%</td>
</tr>
<tr>
<td>SAC305</td>
<td>100mm</td>
<td>115.70mm</td>
<td>15.70%</td>
</tr>
<tr>
<td>Sn63Pb37</td>
<td>100mm</td>
<td>127.39mm</td>
<td>27.39%</td>
</tr>
</tbody>
</table>

Thermal and electrical conductivity

- **LMPA-Q**: Green
- **SnBi(Ag)**: Yellow
- **SnPb(Ag)**: Blue
- **SnCu, SACX, Sn100C SAC**: Orange

**Thermal conductivity** (W/m.K)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Thermal Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
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<tr>
<td>30</td>
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<td>40</td>
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<td>50</td>
<td>50</td>
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<tr>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>

**Electrical conductivity** (MS/m)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Electrical Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
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<td>20</td>
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<td>30</td>
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<tr>
<td>40</td>
<td>40</td>
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<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>

**Note**

- A 1mm² LMPA-Q solder joint has a resistance of about 264µΩ
- A 1mm² SAC305 solder joint has a resistance of about 149µΩ

Acceptable thermal and electrical conductivity for electronics, better than SnBi(Ag)
Intermetallic thickness on Cu

SAC 305: ~1-4μm

LMPA™-Q: ~1-5μm

Lower intermetallic thickness, no micro-cracks

Ageing: 1000H@85°C

SAC 305: ~2-4,5μm

LMPA™-Q: ~2-4μm

Acceptable intermetallic growth and grain coarsening, no micro-cracks
FATIGUE CYCLING ANALYSIS

TEST DESCRIPTION

- Component:
  - QFN 9x9 mm
    - Mold 1: CTE = 7 ppm/°C
    - Mold 2: CTE = 15 ppm/°C
  - Daisy Chain component
- PCB:
  - 1.6 mm thick FR4
- Test condition:
  1. Thermal Cycling: -40°C to +125°C
  2. Bending cycling: 3 mm displacement @ 125°C
- Measurement:
  - In situ resistance measurement
IMPACT OF MOLD CTE ON QFN RELIABILITY

Four Point Bending Experiment

- Equal stress in the area between the inner bars
- Similar shear loading as with thermal cycling
- Test performed at fixed temperature

RESULTS
THERMAL CYCLING -40°C TO +125°C

Mold 1 (7 ppm/°C)
- SAC305
- Low Ag SAC
- SnBi alloy (LMFA-Q)

Mold 2 (15 ppm/°C)
- SAC305
- Low Ag SAC
- SnBi alloy (LMFA-Q)

RESULTS
4PT BENDING CYCLING
### OVERVIEW OF TEST RESULTS

#### Thermal cycling

<table>
<thead>
<tr>
<th></th>
<th>QFN’s with mold 1 (7 ppm/°C)</th>
<th>QFN’s with mold 2 (15 ppm/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAC305</td>
<td>N63% = 141</td>
<td>N63% = 1740</td>
</tr>
<tr>
<td>SACX</td>
<td>N63% = 241</td>
<td>N63% = 1678</td>
</tr>
<tr>
<td>LMPA-Q (SnBi)</td>
<td>N63% = 2537</td>
<td>No failure up to 4250 cycles</td>
</tr>
</tbody>
</table>

#### Bending cycling

<table>
<thead>
<tr>
<th></th>
<th>Test performed at 100°C</th>
<th>Test performed at 125°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>SACX</td>
<td>N63% = 2907 cycles</td>
<td>Not tested</td>
</tr>
<tr>
<td>LMPA-Q (SnBi)</td>
<td>N63% = 1738 cycles</td>
<td>N63% = 1822 cycles</td>
</tr>
</tbody>
</table>

### FAILURE ANALYSIS

- **SAC305**
- **SAC0307**
- **SnBi (LMPA-Q)**

![Images of SAC305 and SAC0307 failure analysis](images)
OTHER RELIABILITY TESTS

Vibration testing

→ High accuracy measuring device: SMD reflow soldered with DP 5600 LMPA™
  Through hole hand soldered with LMPA™ solder wire.

→ BS EN 60945: Section 8.7.2.

→ Resonance search
  - 5 Hz and up to 13.2 Hz with a displacement of +/-1 mm.
  - 13.2 Hz and up to 100 Hz with constant maximum acceleration of 7 m/s² (0.7 g)
  - Testing in X, Y and Z axis

→ Vibration Endurance.
  - 2 hour endurance test at the noted resonant points or at 30 Hz if Q<5

→ X: 2 hrs at 82,92 HZ, 3 g pk acceleration
→ Y: 2 hrs at 30 HZ, 3 g pk acceleration
→ Z: 2 hrs at 30 HZ, 3 g pk acceleration

→ The units exhibited no signs of damage or misalignment after the vibration test.

→ ICT and functional test after vibration test: pass

Result: Pass
Destructive comparative vibration testing: LMPA™ vs SAC305

→ High accuracy measuring device: SMD reflow soldered with DP 5600 LMPA™ and SAC 305
  Through hole hand soldered with LMPA™ solder wire and SAC 305

→ X-axis 30min vibration endurance

<table>
<thead>
<tr>
<th>Test sequence</th>
<th>Frequency</th>
<th>Acceleration</th>
<th>LMPA™</th>
<th>SAC 305</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30Hz</td>
<td>18g</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>2</td>
<td>30Hz</td>
<td>20g</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>3</td>
<td>30Hz</td>
<td>21g</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>4</td>
<td>30Hz</td>
<td>22g</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>5</td>
<td>50Hz</td>
<td>25g</td>
<td>Pass</td>
<td>Fail</td>
</tr>
</tbody>
</table>

SAC 305 fails first

Shock testing

→ High accuracy measuring device: SMD reflow soldered with DP 5600 LMPA™
  Through hole hand soldered with LMPA™ solder wire.


→ 3 Shocks in each direction (pos./neg.) of 3 axes: 18 shock in total

→ X: Peak Acceleration of 10g(*) Half Sine with a pulse width of 11 milliseconds.
  Y: Peak Acceleration of 30g Half Sine with a pulse width of 11 milliseconds.
  Z: Peak Acceleration of 30g Half Sine with a pulse width of 11 milliseconds.

* 10g in X was used because more force disconnected the sensor from the measuring setup.

10 g is about 4X the force a mobile phone experiences when dropping from 1 m on a concrete floor.

→ The units exhibited no signs of damage or misalignment after the shock test.

→ ICT and functional test after shock test: pass

Result: Pass
CONCLUSIONS

Conclusions:

- SnBi based low melting temperature solder LMPA-Q has large benefits in processability and cost
- Reliability tests for large QFN component show up to 12 times higher life time than for SnAgCu solder
- Vibration and shock reliability tests show similar life time as for SnAgCu

Future:

- Further testing need to be done to fully confirm the improved reliability, also for other components
- Material characterisation for creep behaviour and fatigue empirical law