Thermal and mechanical reliability tests of plastic core solder balls

Author: Maaike M. V. Taklo
Company: SINTEF
Email: mvi@sintef.no
Outline

1) Motivation
2) Design and assembly
3) Environmental exposure
4) Electrical testing
5) Failure analysis
6) Conclusions and further work
PCSBo, present status

For Wafer Level Chip Scale Packages (WLCSP)
PoP application processors, 3D-WLP CMOS sensors,
large size Si-BGA packages

- www.sekisuichemical.com
- 3D Packaging, Yole, Issue 24, August 2012, page 12-13
Motivation for use of PCSB in our case

Intended for an application subsea where reliability is of primary concern

1) Render LOW CTE PCB superflueous
   1) Reduced cost
2) Render underfill superflueous
   1) Reduced cost
   2) Rework simplified
   3) No lack of underfill
   4) No cracks in underfill

- R. Johannessen, F. Oldervoll, H. Kristiansen, H. Tyldum, H-V. Nguyen, Knut Aasmundtveit, Investigation of Compliant Interconnect for Ball Grid Array (BGA), Proceedings of EMPC 2009, Rimini, Italy
- Maaike M. V. Taklo, Andreas Larsson, Astrid-Sofie B. Vardøy, Helge Kristiansen, Lars Hoff, Knut Waaler, "Compliant Interconnects for Reduced Cost of a Ceramic Ball Grid Array Carrier", ECTC 2012, San Diego, USA
Design of carrier and board

- **Carrier**
  - LTCC, 8 layers, CTE 6.3 ppm/K, from VTT, thickness 1 mm³
  - Ag filled vias (150 µm)
  - Pads 250 or 275 µm, Cu with ENIG (4 µm Ni, >120 nm Au)

- **Board**
  - FR-4, 16-20 ppm/K, thickness 1.6 mm³
  - Pads 250 or 275 µm, NSMD, Cu with ENIG (5 µm Ni, >10 nm Au)

- **PCSB**
  - Micropearl SOL 310 µm, 25 µm Sn3.5%Ag, 10 µm Cu (with Ni underneath?)

- **Design:** Daisy chain structure and Kelvin structures
Balling of carrier

- PCSBs soldered directly to pads on LTCC
- MARTIN Reball 03.1 unit
- Fluxing agent: IF 8300-4 BGA gel flux
- Reflown for 110 s at 260 °C
- Inspection with SEM (JEOL JSM-5900LV)
Assembly of carrier onto board

- Paste: SAC305, Grade 5, Stencil 80 µm
- Solder print inspection
  - White light interferometry
  - Veeco Wyko NT9800
- Vapor phase soldering at 230°C
  - Carrier and connectors onto the board
  - 250 µm: 16 samples, 275 µm: 18 samples
- Visual inspection with ERSASCOPE

Target a distinct shape of the spheres

Shear tests of early results

Shear tester: Dage 2400A

<table>
<thead>
<tr>
<th>Pad on LTCC (µm)</th>
<th>Pad on PCB (µm)</th>
<th>Ball</th>
<th>Stencil (µm)</th>
<th>Strength (kgF)</th>
<th>PCSBs left on PCB</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>250</td>
<td>Normal</td>
<td>100</td>
<td>6.1</td>
<td>64</td>
</tr>
<tr>
<td>250</td>
<td>250</td>
<td>PCSB</td>
<td>100</td>
<td>11.6</td>
<td>64</td>
</tr>
<tr>
<td>250</td>
<td>250</td>
<td>PCSB</td>
<td>100</td>
<td>5.8</td>
<td>58</td>
</tr>
<tr>
<td>250</td>
<td>250</td>
<td>PCSB</td>
<td>80</td>
<td>4.9</td>
<td>65</td>
</tr>
<tr>
<td>275</td>
<td>275</td>
<td>PCSB</td>
<td>100</td>
<td>5.5</td>
<td>65</td>
</tr>
<tr>
<td>275</td>
<td>300</td>
<td>PCSB</td>
<td>100</td>
<td>8.5</td>
<td>60</td>
</tr>
<tr>
<td>275</td>
<td>275</td>
<td>PCSB</td>
<td>80</td>
<td>4.4</td>
<td>47</td>
</tr>
<tr>
<td>300</td>
<td>300</td>
<td>PCSB</td>
<td>100</td>
<td>8.1</td>
<td>66</td>
</tr>
<tr>
<td>300</td>
<td>300</td>
<td>PCSB</td>
<td>100</td>
<td>8.2</td>
<td>62</td>
</tr>
<tr>
<td>325</td>
<td>300</td>
<td>Normal</td>
<td>100</td>
<td>20.4</td>
<td>64</td>
</tr>
</tbody>
</table>

Most frequent: Ball removed from LTCC

Less frequent: Ball removed from FR4

Acceptable strength of selected design
Thermal cycling

In situ electrical measurements
Removed in the image: Plastic "housing"

- JESD22-A104 between -55 to +85 °C, 10 °C/min ramp 10 min soak time, 920 #
- Agilent 34970A data acquisition unit
- Agilent 20 channel multiplexer card
- One batch measurement per minute
- K-type thermocouple
- 7 samples of each type (3 in situ)
Mechanical shock

- According to JESD22-B104
- 10 times 200 g and 400 g
- 1 ms pulse, 6 directions
- Visual inspection
  - Optilia – BGA inspection System
Random vibrations

- According to JESD22-B103
- 5-500 Hz, 2.4 g RMS peak
  - Average energy input for each frequency
  - Sequence randomly selected
- 3 directions, 20 min/axes
Electrical testing

• Keithley 3706 multimeter
  • Keithley 3721 multiplexer card
  • Connected by USB to a PC
• Controlled by software developed in LabVIEW
  • Using Keithley 3700 Series Instrument Driver
  • 4-wire resistance measurements
  • Scanning 14 channels in sequence
  • Each resistance measurement repeated 8 times
  • Average and standard deviation over 8 repeated readings

• Daisy chain structure (53 interconnects)
• Kelvin structures (13)
Failure analysis, electrical failures - as assembled

Also "bad" samples were further tested
- If one or more Kelvin structures were complete
- Number of complete Kelvin structures was recorded

Average resistance of complete Kelvin structures
- 250 µm (#78): 1.1 mΩ
- 275 µm (#136): 0.9 mΩ
Failure analysis, electrical failures after exposures

- **Thermal cycling**
  - 7 failures
  - 250°C, 275°C

- **Mechanical Shock**
  - 4 failures
  - 0 failures

- **Random Vibrations**
  - 5 failures
  - 0 failures
Failure analysis, SAM by Melexis

- 14 samples sent to SAM after TC
  - One broken during shipment
- Limited area between connectors for transducer
  - Not all PCSBs could be examined
- Focus selected in middle of ball
  - Failures in pad regions should also be visible

White spots might represent cracks, but no clear correlation was found. Resolution was too low.
Failure analysis, cross sections

- **Embedded in epoxy resin**
  - Coarse grinding (SiC sand paper 320)
  - Fine grinding (SiC 1200 and 4000)
  - Polishing on a cloth, 6µm diamond particles
  - Final polishing, colloidal silica (~ 40 nm)
    - In a basic solution (pH ~10)
    - Enhances the contrast at some grain boundaries

- **Light Microscopy**: Neophot 32 metallographic microscope
- **FE-SEM**: FEI Nova NanoSEM 650
- **EDS**: Oxford X-Max50 Silicon Drift Detector (SDD) (20 kV)

Control of dimensions

One row per sample, one image per PCSB
Cross sections, as assembled (good)

Large variation in shapes, but comparable with publications by e.g. Sekisui

Conpart achieve more distinct shape, but have no solder on sphere

250 µm pads

275 µm pads
Cross sections, as assembled (bad)

No clear trends, but some initial cracks in Ag vias and some unbonded PCSBs observed.

Crack initiations?

250 µm pads

275 µm pads
IMC after mechanical shock only

Studied sample: 275 µm design, zero fails as assembled
3 failing Kelvin structures after mechanical shock

EDS: mainly Cu$_6$Sn$_5$ but also some Ni

Cu$_6$Sn$_5$ result in a lower Tm than Ni$_3$Sn$_4$, thus favoured
Ni and Cu have similar properties and are fully dissolved in each other
IMC after thermal cycling

Studied sample (275 μm design) had zero fails before testing and a 10 fold increase in resistance for the Daisy chain after thermal cycling.

General observation: IMC similar to samples studied after shock

→ Most observed IMC formed during assembly

Thin layer Cu$_3$Sn
Maybe from TC

Thick layer Cu$_6$Sn$_5$
Failures after TC, cracks

Clearly dominating failure mode

Less frequent failure mode

Light microscope
Two 250 µm design samples

SEM
Backscattered electrons

SEM
Secondary electrons
Propagation of cracks

- Appears not to follow grain boundaries of IMC
- Seems to initiate at random failures

- After TC (three samples studied in details in SEM)
  - All with cracks at LTCC pad
  - 20-50% with cracks in solder
  - Similar for 250 and 275 µm pad design
Failures after TC and MS or RV

- After only Mech. shock or Rand. vibrations (four samples studied in LM)
  - No cracks observed
    - Cracks might exist in the LTCC pad (SEM required)
  - Similar for 250 and 275 µm pad design

- After TC and Mech. shock or Rand. vibrations (four samples studied in LM)
  - Initiations of cracks observed
    - Cracks might exist also in the LTCC pad (SEM required)
Conclusions and further work

• Our case: PCSB show promising properties
  • Performed well in initial screening tests
  • Thermal followed by mechanical exposure was tested
  • No underfill was required
  • Traditional FR-4 was combined with LTCC
    • More testing required in case of full qualification
    • Improved LTCC design

• General: More challenging assembly than normal BGAs
  • Less solder available for self alignment
  • But - if successfully assembled, superior reliability achieved
    • Considerations of inclusions of Ni
    • Improvement of soldering process
Thank you

The ESiP team is indebted to the national support of the public authorities from the 9 participating European countries and the ENIAC Joint Undertaking

This work was initiated in the project 187971 ReMi sponsored by the BIA program of The Norwegian Research Council