Interconnects based on metal coated polymer spheres for improved reliability

Maaike M.V. Taklo¹, Andreas Larsson¹, Knut Aasmundtveit² and Helge Kristiansen³

¹ SINTEF ICT, 0314 Oslo, Norway
² Vestfold University College, 3103 Tønsberg, Norway
³ Conpart AS, 2013 Skjetten, Norway

The presented project, ReMi, is sponsored by the BIA program of The Norwegian Research Council
Outline

- Motivation: Reliability challenges in harsh environments
- Basic properties of metal coated polymer spheres
- Isotropic conductive adhesive
- Anisotropic conductive adhesive
- Ball Grid Array assembly
  - With case studies for each
- Outlook and summary
ReMi: Fine Pitch Interconnect of Microelectronics and Microsystems for use in Rough Environments

- Fine pitch
- Harsh environment
  - Thermal cycling
  - Thermal storage
  - Vibrations
- Project duration 2008 – 2012
- Project size ~0.85 MEUR

Fine pitch

Harsh environments for offshore applications

Large stresses during firing of missiles
Challenges with reliability

- Thermal mismatch of substrate, chip, interconnect and fill materials
  - Thermo mechanical stress during cycling can lead to failures
- Brittle intermetallic phases in interconnects
  - Mechanical stress from shocks/vibrations can lead to failures
- Fine pitch
  - Lack of process control can lead to failures
- How can reliability be improved by introducing metal coated polymer spheres?


Ag Epoxy dispensed on fine pitch MEMS device
Metal Coated Polymer Spheres (MPS)

- Polymer core
  - Dimension controllable by Conpart to <2%
    - “Small” 4-30 µm: Mixed into matrixes at certain volume concentrations
    - “Large” 250-800 µm: Positioned as single balls like regular BGA balls
  - Elastic properties controllable by adjusting chemical contents
    - Collapse or stiff

- Metal coating
  - “Small”: Ni and Au or Ag (20-80 nm layers)
  - “Large”: Cu and Sn (10-25 µm layers)

- Advantages
  - Significantly reduced metal consumption
  - Optimise mechanical properties and electrical conductivity independently
  - Optimise $T_g$ of polymer with respect to matrix
  - Match CTE to that of the matrix
  - Use cure shrinkage to increase particle-particle contact area
Percolation

- Continuous (electrical) network
- Particle to particle interaction
- Strongly dependent on “characteristic length”
  - $L/d$
- Dependent on “orientation” of particles (non-spherical)

Rheology: Handling of adhesive

- Viscosity increases as volume % is increased
  - Lubricants
  - Solvents
- Shear-flow induced orientation
- MPS: Larger volume % possible and no orientation

Kristiansen et al., Pan Pacific 2009
Mechanical properties of MPS

- Measurements performed with nanoindentation at NTNU in Trondheim, Norway
Isotropic conductive adhesives (ICA)

- Used in electronics packaging and interconnect for decades
  - Composite material
    - Adhesive resin
    - Conductive particles (metals)
  - Typically known as silver epoxies
    - Epoxy adhesive loaded ≈ 30% Ag (volume %)
    - Matrix and fillers are very different materials
      - E-modulus ratio: 2-orders of magnitude
      - Large CTE miss-match
  - Micro-cracking between filler and matrix
  - Brittle behaviour
    - Introduce plasticisers, reduce $T_g$ of matrix
      - Increases CTE miss-match
  - Replace Ag with MPS to improve reliability
ICA case study: MEMS fuse

- MEMS device in SOI wafer
- Assembly directly on PCB
- ICA with 3-4 and 30 µm MPS
- Stencil printing issues for 30 µm

- Thermal cycling of chips assembled in parallel on large test boards
- Thermal cycling followed by firing tests of chips assembled on smaller boards
- Electrical testing, shear strength measurements and cross section inspection: Viable technology for the purpose!
Electrical results

- ICA-A: 30 µm Ag coated MPS
- ICA-B: 4 µm Ni and Au coated MPS

<table>
<thead>
<tr>
<th>ICA type</th>
<th>Board number</th>
<th>Number of temp cycles</th>
<th>$R_{\text{average}}$ (Ω) after temp cycling (std dev)</th>
<th>$R_{\text{average}}$ (Ω) after firing (std dev)</th>
<th>Percent change</th>
<th>Number of measured resistances</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICA-A</td>
<td>I1</td>
<td>100</td>
<td>0.675 (0.246)</td>
<td>0.733 (0.326)</td>
<td>8.6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>I2</td>
<td>10</td>
<td>0.224 (0.094)</td>
<td>0.205 (0.092)</td>
<td>-8.5</td>
<td>5</td>
</tr>
<tr>
<td>ICA-B</td>
<td>I3</td>
<td>100</td>
<td>0.217 (0.084)</td>
<td>0.257 (0.105)</td>
<td>18.4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>I4</td>
<td>10</td>
<td>0.082 (0.022)</td>
<td>0.097 (0.033)</td>
<td>18.3</td>
<td>6</td>
</tr>
</tbody>
</table>

Anisotropic conductive adhesive/film (ACA/ACF)

- Provides unidirectional electrical conductivity
- The directional conductivity → relatively low volume loading of conductive filler (5-20 vol%)
- Fine pitch implementation
- ACF is commonly used in LCD screens

http://www.acffilm.com/
ACF case study: Fingerprint sensor

• MEMS onto ASIC, fine pitch
• Anisotropic conductive film (ACF)
  – Film from subcontractor (using MPS from Conpart)
  – Lamination
  – Amount of MPS below percolation limit

• Research tasks
  – Assembly (VUC/Tampere)
    • Lamination (below $T_g$)
    • Bonding (above $T_g$)
  – Cross-section & surface analysis
  – Thermal analysis ($T_g$)
    • DSC
  – Testing
    • “Reflow”
    • Thermal shock cycling
    • Humidity
ACA on wafer scale: Bonding for MEMS

- Combining adhesive wafer level bonding (BCB) and principle of ACA
- MPS trapped in pad regions
- Applicable e.g. for MEMS wafers requiring electrical connection to cap wafer with TSV or electrodes
- Plasma-FIB image (by FEI) showing 4 µm MPS trapped in a bonded region assuring electrical connection between the wafers

Taklo et al., Device Packaging Conference, March 2011
Ball Grid Array balls (BGA)

- Transition from SnPb to SAC has resulted in reduced cycles to failure
- Combination of
  - Thermal expansion miss-match
  - Non-compliant ball
- Causes reliability issues
  - Severe cyclic strain in solder
  - Severe stress in component
- Limits maximum size of component / Number of I/O’s
  - Replace SnPb/SAC with MPS to improve reliability

Whalley, HDP Feb 2010

http://www.bga.net/

http://www.sekisui-fc.com/

RoHS, since 1. July 2006
BGA case study: Ceramic package

- MPS with solder as BGA
  - Spheres from Sekisui and Conpart
- References: SnPb and SnAgCu BGAs
- Solder onto LTCC

- Mounting onto PCB
- Reliability studies

310 µm balls from Sekisui on LTCC
Outlook and summary

- **Case study I, ICA for a MEMS fuse**
  - Satisfactory results and the product is presently further developed
- **Case study II, ACA for a Fingerprint sensor**
  - Results show satisfactory resistance measurements and good reliability from stress tests
  - Closing tests are performed this spring and all results are to be compiled in a coming journal paper in 2011
- **Case III, BGA with MPS for a ceramic package**
  - Reliability tests to be performed

- All results achieved so far support the theory about increased reliability, in particular with regard to shock and thermal cycling, due to the increased compliance of a system with MPS